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Supply Chain Risk Management System in the Context of Digital Transformation

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Abstract: In the context of digital transformation, traditional supply chain risk management faces challenges. This study explores how digital technologies reconstruct risk management and enhance resilience. Through literature analysis and Huawei's case, we find IoT, big data, and AI enable real-time visibility and predictive capabilities, while introducing new risks. A digital system integrating intelligent identification, assessment, response, and monitoring is proposed. Resilience hinges on visibil ity, agility, and adaptability. Huawei's practices validate the framework. This provides guidance for enterprises to strengthen supply chains via digitalization.

Keywords: Supply chain risk management; Digital transformation; Supply chain resilience.

1. Introduction

In an environment marked by intensifying global competition and growing uncertainties, supply chain risk management has become a vital component of corporate strategic governance. Concurrently, the wave of digital transformation is fundamentally reshaping business operations and management practices. Traditional supply chain risk management frameworks prove inadequate in addressing increasingly complex risk landscapes, necessitating systematic restructuring and enhanced resilience development.

The purpose of this study is to explore how digital technologies can be utilized to reform the supply chain risk management system and enhance supply chain resilience, thereby better addressing various internal and external risks. The research employs literature analysis, case studies, and other methodologies. Through methods such as theoretical modeling, this study systematically analyzes the new characteristics and requirements of supply chain risk management in the context of digital transformation. The findings hold significant theoretical and practical value for enterprises seeking to enhance their supply chain risk management capabilities in the digital age.

2. Analysis of the Current State of Supply Chain Risk Management

2.1. Global Development Overview

The global supply chain is undergoing unprecedented transformations in a century. A 2023 McKinsey research report reveals that annual losses incurred by companies due to supply chain disruptions now account for 6–8% of their revenue, far exceeding the 2.7% recorded in 2000. Logistics disruptions caused by the COVID-19 pandemic reduced global GDP by $3.4 trillion, while the energy supply chain restructuring triggered by the Russia-Ukraine conflict drove Europe's manufacturing PMI index plummeting to 33.1 in October 2022. [1] Against this backdrop, traditional risk management approaches have revealed three major shortcomings:

Response lag: Risk assessments based on historical data struggle to detect black swan events—such as the 2021 Texas cold snap in the United States that forced production halts at Samsung's wafer fab and triggered a global shortage of automotive chips.

System vulnerability: Toyota's Just-In-Time (JIT) production model revealed significant flaws during the pandemic, with disruptions from a single supplier causing 45% of automakers to halt production [2].

Fragmented decision-making: Only 29% of enterprises achieve cross-departmental risk data sharing.

2.2. Purpose of Research

Traditional embroidery patterns often have strong freehand brushwork characteristics. For designers, they do not pursue the perfect proportion too much, but pay more attention to the meaning of the pattern itself and the emotional effect brought by the pattern. Traditional embroidery patterns have a very strong freehand effect. In particular, part of the pattern only through some simple lines, to draw the content, can be very vivid expression of the original features. In the development of embroidery art, designers need to grasp the characteristic expression of freehand brushwork, recognize the inherent laws of things, and then show the profound connotation of embroidery art.

2.3. Research Topic

This study focuses on supply chain risk management, aiming to explore its theoretical foundations, practical applications, and future development. Through analysis of relevant literature and case studies, the paper addresses the following questions: 1) What are the types of supply chain risks? 2) How can these risks be effectively managed? 3) What challenges and opportunities will supply chain risk management face in the future? The paper structure comprises an introduction, a literature review, risk types and management strategies, case analyses, and conclusions.

3. Literature Review on Supply Chain Risk Management

Research on supply chain risk management originated in the 1990s. Early scholars such as Christopher and Peck developed a framework for supply chain risk management, emphasizing the sources and impacts of risks. Their study

categorized supply chain risks into internal and external risks; internal risks encompass process-related issues within the supply chain, while external risks involve environmental factors such as political, economic, and natural events. Subsequent research, exemplified by Tang, expanded risk management strategies by introducing a four-step framework comprising risk identification, assessment, mitigation, and monitoring.

In recent years, driven by digital transformation, scholars have increasingly focused on the role of technology in risk management. For instance, Ivanov examined the application of blockchain and artificial intelligence in enhancing supply chain resilience. Moreover, the use of digital technologies in supply chain risk management has garnered growing attention. Research by Fan et al demonstrates that artificial intelligence and machine learning can significantly improve the accuracy of risk prediction by analyzing big data to identify potential threats such as demand fluctuations or supply chain disruptions. Dolgui et al also highlighted the potential of blockchain technology in this context, demonstrated that digital solutions enhance supply chain transparency and traceability, thereby reducing risks of fraud, theft, and disruptions. IoT devices are also employed for real-time monitoring of supply chain activities, enabling companies to identify risks early—such as abnormal warehouse temperatures or transportation delays. Huo et al further emphasized that big data analytics can integrate multi-source data (e.g., social media and sensor data) to develop dynamic risk assessment models. These digital tools not only improve the efficiency of risk management but also strengthen the overall resilience and adaptability of supply chains. However, the study also noted that digital applications face Challenges such as data privacy and cybersecurity issues require further exploration [3].

These studies demonstrate that supply chain risk management has evolved from mere cost control to strategic risk management, emphasizing resilience and sustainability. Overall, the existing literature provides a solid theoretical foundation for this study, but its validity still requires validation through practical case analyses.

4. Types of Supply Chain Risks and Management Strategies

4.1. Types of Supply Chain Risks

Supply chain risks can be classified based on their origin and nature, primarily including the following types:

(1) Supply risk: refers to the risk of disruptions in the supply of raw materials or components, such as supplier bankruptcy, quality issues, or material shortages. Given the high interdependence of global supply chains, a single-supplier model can amplify this risk.

(2) Demand risk: Risks arising from demand fluctuations or inaccurate forecasts. For example, market changes or unexpected events (such as a pandemic) may cause demand to drop or rise sharply, requiring companies to adjust inventory and production plans.

(3) Logistics risks: Risks during transportation and warehousing, including traffic accidents, natural disasters, or customs delays. These risks may lead to delivery delays and increased costs.

(4) External risks: These stem from environmental factors outside the supply chain, such as political instability, economic crises, natural disasters, or geopolitical conflicts. The COVID-19 pandemic serves as a typical example of an external risk event that highlighted the vulnerability of global supply chains.

These risk types are interconnected and can trigger a ripple effect; for instance, a supplier disruption may impact the entire supply chain.

4.2. Supply Chain Risk Management Strategy

Effective supply chain risk management typically employs a systematic framework comprising four stages: risk identification, risk assessment, risk response, and risk monitoring.

(1) Risk Identification: Identify potential risks using SWOT analysis (strengths, weaknesses, opportunities, threats) or expert interviews. Enterprises can use tools such as risk maps to visualize risk sources.

(2) Risk assessment: Quantifies the impact and probability of risks. For example, a probability-impact matrix is used to evaluate risk severity. Modern approaches also incorporate big data and AI for predictive analysis.

(3) Risk Response: Based on risk assessment results, appropriate strategies can be implemented. These include modifying supply chain design by diversifying suppliers to reduce dependency and mitigate risks; mitigating risk impacts through inventory buffers or backup suppliers; transferring risks to third parties via insurance or contractual provisions; and for low-probability, low-impact risks, enterprises may choose to accept them and monitor their occurrence.

(4) Risk Monitoring: Continuously track risk changes and adjust management strategies. Digital tools such as ERP systems and the Internet of Things provide real-time data support.

Furthermore, building supply chain resilience is a key strategy, encompassing enhanced resilience and adaptability. For instance, adopting a dual-source supply approach or investing in sustainable practices can help mitigate uncertainties.

Theoretical foundations of supply chain risk management

Supply chain risk management refers to the process by which enterprises identify, assess, and address potential risks across all supply chain segments to ensure its continuous and stable operation. Traditional supply chain risk management primarily focuses on highly predictable risk types such as supplier risk, logistics risk, and demand risk, employing relatively limited approaches that rely mainly on empirical judgment and static assessments [4].

With the increasing complexity of supply chains and growing uncertainties in the external environment, traditional risk management models face numerous challenges. First, the diversity and complexity of risks have significantly increased; beyond traditional risks, new types such as cybersecurity risks and data privacy risks continue to emerge. Second, the pace of risk propagation has accelerated, with enhanced interconnections across supply chain segments, enabling localized risks to rapidly evolve into systemic risks. Finally, traditional static risk assessment methods struggle to adapt to rapidly changing environments, while the timeliness required for risk management decisions has become paramount.

Therefore, in addressing the practical challenges of supply chain risk management, it is imperative to vigorously promote digital transformation and upgrading as a means to mitigate these risks.

5. Supply Chain Risk Management and Digital Transformation

5.1. The Impact of Digital Transformation on Supply Chain Risk Management

Digital transformation has brought revolutionary changes to supply chain risk management. On one hand, digital technologies such as the Internet of Things (IoT), big data, and artificial intelligence provide new tools and methods for risk management. For example, IoT devices enable real-time monitoring of operational status across all supply chain stages; big data analytics can identify potential risk patterns and correlations; and AI algorithms facilitate intelligent risk prediction and automated response.

On the other hand, digital transformation has introduced new types of risks and management challenges. Data security risks, system reliability risks, and technological dependency risks have emerged as critical areas requiring heightened attention. Furthermore, the virtualized and networked nature of digital supply chains has made risk propagation pathways more complex, making traditional linear risk management approaches ill-suited to networked environments [5].

Digital transformation has also transformed how supply chain risk management is organized. Cross-departmental and cross-enterprise collaborative risk management has become increasingly vital, with data sharing and process integration serving as key drivers for enhancing risk management efficiency. Meanwhile, the demand for real-time and precise risk management decisions has grown significantly, necessitating a shift from traditional periodic risk assessment approaches to continuous monitoring and dynamic adjustments.

5.2. Reconstruction of the Supply Chain Risk Management System Based on Digital Technology

In the context of digital transformation, the supply chain risk management system requires systematic restructuring. The new management framework should encompass four key components: risk identification, risk assessment, risk response, and risk monitoring, with each component fully leveraging the enabling potential of digital technologies.

In risk identification, technologies such as social media monitoring, IoT sensors, and supply chain digital twins can be employed to expand the scope of risk surveillance and enhance the comprehensiveness and timeliness of risk detection. By establishing a multi-dimensional risk signal collection network, a comprehensive scan of both internal and external supply chain environments can be achieved.

In the risk assessment phase, big data analytics and artificial intelligence algorithms can process vast amounts of structured and unstructured data to identify potential risk patterns and correlations. Machine learning models continuously enhance the accuracy of risk assessments, while blockchain technology improves the authenticity and traceability of risk-related data.

Risk response strategies also require digital transformation. An intelligent risk decision-support system enables managers to swiftly develop optimal response plans, while a digitalized emergency response management platform enhances coordination and operational efficiency. Furthermore, supply chain visualization tools facilitate visualized management and dynamic adjustment of response measures [6].

Digital transformation of risk monitoring processes is particularly crucial. Establishing a real-time risk dashboard that integrates various risk metrics enables dynamic, visualized risk tracking. Utilizing predictive analytics allows for forward-looking assessments of risk trends. Furthermore, a digital risk feedback mechanism continuously enhances the effectiveness of the entire risk management system.

5.3. The Connotation and Pathways of Building Resilient Supply Chains

Supply chain resilience refers to the ability of a supply chain system to maintain essential functions, recover rapidly, and adapt to new environments when disrupted. In a digital context, building supply chain resilience requires focusing on three key elements: visibility, agility, and adaptability.

Visibility refers to the extent of real-time monitoring of operational status across all stages of the supply chain. Achieving end-to-end supply chain visualization through digital technologies forms the foundation for enhancing resilience. This encompasses the real-time sharing and transparent management of critical information such as order status, inventory levels, logistics trajectories, and production capacity.

Agility emphasizes a supply chain's ability to respond rapidly to changes. The pathways for enhancing agility through digital empowerment include: establishing a modular supply chain architecture for quick reconfiguration; deploying intelligent demand sensing and forecasting systems; and achieving elastic resource allocation and dynamic scheduling.

Adaptability refers to a supply chain's capacity for long-term evolution and learning. By leveraging digital technologies, we build a learning-oriented supply chain that continuously optimizes risk management strategies through historical data analysis. Additionally, we develop digital scenario planning tools to simulate and prepare for various potential future scenarios.

Resilience development also requires alignment between organizational culture and governance mechanisms. It is essential to foster risk awareness among all employees and create a cultural environment that encourages innovation. Regarding governance mechanisms, responsibilities for risk management during digital transformation must be clearly defined; a cross-functional resilience management team should be established, along with the development of digital resilience assessment metrics and incentive mechanisms.

6. Case Analysis and Application

6.1. Huawei's Practices in Supply Chain Risk Management

As a global leader in ICT infrastructure and smart terminal solutions, Huawei's supply chain network spans the globe, encompassing over 2,000 suppliers and tens of thousands of components. Amid multiple challenges such as U.S. sanctions and the COVID-19 pandemic, Huawei has restructured its supply chain risk management system through digital transformation, demonstrating exceptional resilience. This section will provide an in-depth analysis of Huawei's specific practices in supply chain risk management.

In building a digital risk identification system, Huawei has established the industry-leading "Supply Chain Risk Radar" system, which integrates data sources from multiple dimensions:

(1) Supplier operational data: Real-time access to key suppliers' production plans, inventory levels, equipment utilization rates, and other operational metrics via the EDI system.

(2) Logistics Monitoring Network: Over 5,000 IoT sensors have been deployed to track the transportation status and location of critical materials in real time.

(3) Macroeconomic monitoring: Utilizes natural language processing technology to analyze over 200 global news sources and government announcements, identifying potential policy and geopolitical risks.

(4) Social media analysis: Monitoring key personnel changes and technical discussions on platforms such as LinkedIn and Twitter to identify supply chain talent risks and technical risk assessment areas. The system processes over 10 TB of data daily, enabling early detection of more than 80% of supply chain risk events with a lead time of 3–6 months. For example, prior to U.S. sanctions in 2019, the system had already identified potential risks by analyzing records from U.S. congressional hearings and think tank reports.

Innovating intelligent risk assessment models, Huawei developed a machine learning-based & quot; Supply Chain Health Score Model, & quot; which comprises 128 evaluation indicators categorized into five major dimensions:

(1) Supplier Stability (30% weight): Includes financial condition, management stability, labor relations, etc.

(2) Technical dependency (weight: 25%): Evaluates the feasibility of alternative solutions and the costs associated with technology migration.

(3) Geographic risk (weight: 20%): Factors include political stability and the likelihood of natural disasters in the supplier's location.

(4) Business Continuity (Weight: 15%): Evaluate the supplier; disaster recovery capabilities and recovery plans.

(5) Compliance Risk (Weight: 10%): Includes compliance requirements related to export controls and data privacy.

6.2. Huawei's Digital Emergency Response Mechanism

Huawei has established a three-tier emergency response system:

(1) Daily Monitoring: The Supply Chain Operations Center monitors risk indicators 24 hours a day.

(2) Rapid Response: Establish a "Supply Chain Operations Center" comprising departments such as procurement and production.

(3) Strategic Decision: The Supply Chain Continuity Committee, led by the rotating CEO.

During the 2021 chip shortage crisis, Huawei utilized this mechanism to: complete a global chip inventory audit within 72 hours; adjust design specifications for over 100 product models within one week; reach agreements with 20 alternative suppliers within two weeks; and re-plan global logistics routes within one month.

Huawei's practices demonstrate that comprehensive digital transformation and systematic resilience strategies can help enterprises maintain supply chain stability in complex and volatile environments. Its experience provides valuable references for other companies, particularly in areas such as self-reliance and control in key technology sectors, digital risk management, and global expansion.

7. Conclusion

This paper investigates the reconstruction and resilience enhancement of supply chain risk management systems in the context of digital transformation. Key findings include: digital technologies provide new methods and tools for supply chain risk management, while also introducing novel risk types and management challenges; the restructuring of management systems based on digital technologies must encompass the entire process of risk identification, assessment, response, and monitoring; supply chain resilience development should focus on three critical dimensions: visibility, agility, and adaptability; Huawei's practices demonstrate that comprehensive digital transformation and systematic resilience strategies can effectively enhance a supply chain's risk resilience.

Future research can be further advanced in the following areas: exploring the application of emerging technologies such as blockchain in supply chain risk management; developing performance evaluation frameworks for digital supply chain risk management; and analyzing the distinct impacts of digital transformation across different industries on supply chain risk management. Additionally, cross-country comparative studies and long-term tracking research will enhance our understanding of this field.

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