Supply Chain Risk Management for stockout prevention: a case study of a multinational retailer in hearing care devices

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Abstract: Supply chain risks are increasingly concerning for business executives, leading to a rise in academic interest in Supply Chain Risk Management (SCRM). However, there is a gap in the existing literature that adequately addresses SCRM in the hearing care industry. This paper addresses this gap by developing a five-phase SCRM framework and applying it to Alpha, a multinational retailer specializing in hearing care products. The phases include supply chain mapping, risk investigation, risk prioritization, risk measurement and threshold definition, and business continuity and monitoring. The methodology integrates qualitative techniques—such as unstructured interviews, focus groups and brainstorming, mapping and categorization, and Eisenhower matrix for risk prioritization—and quantitative techniques— Mean Absolute Percentage Error (MAPE) and Coefficient of Variation of Error (CVE)— to ensure comprehensive risk assessment and management. The framework's effectiveness is demonstrated through a case study on Alpha, validating its utility in identifying and prioritizing supply chain risks and evaluating supplier risk exposure. The findings emphasize the importance of structured monitoring processes, including daily monitoring thresholds and escalation procedures, for maintaining supply chain resilience. A stockout prevention process, focusing on early detection and mitigation of potential disruptions, is proposed and supported by robust supplier communication. Managerial implications include the development of proactive risk management strategies, the establishment of robust supplier communication protocols, and the implementation of continuous monitoring systems to enhance operational resilience and mitigate supply chain disruptions.

Keywords: Supply Chain Risk Management, Risk, Resilience, Stockout

1.Introduction

Supply Chain Risk Management (SCRM) has become increasingly critical due to the complexities and global nature of modern supply chains since risks such as natural disasters, geopolitical issues, and operational disruptions can lead to significant delays and financial losses (Ivanov and Dolgui 2020; Wieland and Wallenburg 2012). The COVID-19 pandemic, for instance, demonstrated how quickly supply chains can be disrupted, leading to shortages and financial stress across industries (Ivanov and Dolgui 2020). Despite their importance, existing SCRM frameworks and models often lack specificity and adaptability to different business contexts, necessitating the development of tailored risk management frameworks (Browning et al. 2023).

Risks can emerge from various sources such as environmental (e.g., natural disasters), organizational (e.g., labor strikes), and network-related issues (e.g., communication failures between organizations) (Gunessee and Subramanian 2020; Lohmer et al. 2020). The uncertainty in the business environment and the intricacies of supply chains increase the likelihood of breakdowns, highlighting the need for robust risk management processes in supply chain management projects (Browning et al. 2023).

Over the past two decades, academics and managers have enriched SCRM with various frameworks, models, and strategies, proposing quantitative and qualitative methodologies to manage supply chains risks (Son 2018; Gurtu and Johny 2021; Cigolini et al. 2022; Franceschetto et al. 2023). Nonetheless, there is a notable gap in the literature regarding SCRM frameworks that are tailored to specific industries and capable of integrating both qualitative and quantitative risk assessment methods (de Oliveira et al. 2017). This study aims to address this gap by developing a comprehensive SCRM framework for Alpha, a multinational retailer in hearing care devices, focusing on effective risk identification and prioritization, and continuous monitoring of inventory levels, lead times, and supplier performance.

The primary objectives of this study are to develop a comprehensive SCRM framework incorporating both qualitative and quantitative methods. Additionally, the study aims to implement the framework in a real-world context, applying it to Alpha's supply chain to demonstrate its practicality and effectiveness. Another key objective is to evaluate the framework's effectiveness by

assessing its impact on supply chain performance, particularly in risk identification, prioritization, and mitigation. Finally, the study seeks to contribute to the SCRM literature by providing insights and recommendations for enhancing SCRM practices.

Hence, two research questions (RQs) were formulated: RQ1: How can a comprehensive SCRM framework be developed to effectively identify and prioritize risks in a supply chain?

RQ2: What are the practical impacts of implementing the SCRM framework in a real-world supply chain context, specifically for a multinational retailer in hearing care devices?

To address these questions, the literature review delves into several key areas: defining risks and risk management frameworks, emphasizing the significance of SCRM and exploring diverse methodologies for constructing effective SCRM frameworks. Following this, the methodology section elucidates the data collection process for the case study and offers a comprehensive overview of the SCRM framework tailored to the retailer Alpha's supply chain. Through the application of this framework, the study enables an in-depth analysis of the upstream segment of Alpha's supply chain, facilitating the identification and prioritization of risks across various sub-segments. Additionally, it evaluates the extent to which Alpha and its suppliers are safeguarded against these risks. Based on the framework, a stockout prevention process has been proposed, focusing on early detection and mitigation of potential disruptions.

The remainder of this paper is structured as follows: in section 2, a literature review is provided. Section 3 explains the methodology of the study. Section 4 introduces the case study, which provides the company description. Section 5 discusses the results of the risk management framework applied to the Alpha's supply chain. Finally, section 6 presents the conclusions along with the limitations and future developments.

2. Literature review

Understanding risk in supply chains has evolved significantly over the decades. Early perspectives, such as those by March and Shapira (1987), conceptualized risk as the variability in possible outcomes, their likelihood, and their subjective values. Building on this foundational understanding, contemporary research delves deeper into the probability and impact of events that can disrupt the supply chain, either directly or indirectly (Garvey et al. 2015; Amico et al. 2022; Amico and Cigolini 2023). These risks can emerge from various sources, such as environmental factors, network issues, and organizational problems (Gunessee and Subramanian 2020; Lohmer et al. 2020).

Importantly, differentiating between risks and disruptions is crucial for effective risk management: while disruptions indicate risks, not all risks lead to disruptions (Gurtu and Johny 2021). Additionally, risk involves measurable probabilities of outcomes, whereas uncertainty entails unknown probabilities (Khan and Burnes 2007). Although there is general agreement that identifying and analyzing risks is essential for managing them, there is no consensus on a standard definition of risk within supply chains (Browning et al. 2023). Browning et al. (2023) show that existing literature reveals a diverse range of focuses within SCRM, including specific domains such as forecasting, risk management, and product and supply chain design. They also highlight various approaches to address these focuses, such as human-augmented forecasting, visual analytics, ad hoc supply chains, design for adaptability and resilience, and digital twins and scenario planning. These variations in focus and approach lead to differing risk management strategies and investigative methods.

Various studies (Gaonkar and Viswanadham 2007; DuHadway et al. 2019) classify supply chain risks into three categories based on impact severity. The first category, deviation, involves minor variations in supply chain parameters without structural changes. The second, disruption, refers to structural changes caused by the unavailability of facilities due to unpredictable human or natural events. The last category, disaster, involves a short-term, irretrievable shutdown of the entire supply chain network due to catastrophic disruptions. Managing these risks requires both preventive measures, which aim to reduce the likelihood of disruptions through robust design, and interceptive measures, which focus on mitigating the impact of disruptions through active intervention (Gaonkar and Viswanadham 2007). Combining these strategies enhances supply chain resilience.

The discipline of risk management encompasses strategies, methods, and supporting tools to identify risks and then to control them to a permissible level (Alhawari et al. 2012). According to Laine et al. (2021), risk management processes should be embedded into the daily activities of an organization, ensuring that risks are continuously monitored and managed. This integration helps in maintaining a consistent approach to identifying, assessing, and mitigating risks across all organizational levels and functions. Moreover, as part of this integrated approach, the risk evaluation process is crucial as it provides essential information that aids in making informed decisions and managing risks effectively.

According to Svensson (2004), Heckmann et al. (2015), and Ivanov and Dolgui (2021), SCRM field focuses on developing methodologies to identify, classify, and mitigate risks within the supply network. This includes managing risks either at the level of individual components (atomistic vulnerability) or across the entire supply chain (holistic vulnerability). Gurtu and Johny (2021) emphasized the critical role of SCRM for companies. They stressed the importance of coordination among supply chain firms to reduce vulnerability, minimize losses, and develop effective risk mitigation strategies.

The risk management framework proposed by De Oliveira et al. (2017) is versatile and applicable across various sectors and industries due to its foundation on standardized activities aimed at mitigating or avoiding risks. The framework encompasses seven steps:

establishing the context, risk identification, risk analysis, risk evaluation, risk treatment, monitoring and critical review, and communication and consultation. These steps ensure a comprehensive approach to managing organizational risk effectively.

According to Hallikas et al. (2004) and Gaudenzi et al. (2023), in typical risk management processes, four main phases are essential: risk identification, risk assessment and prioritization, decision and implementation of risk management actions, and risk monitoring. Risk identification makes decision-makers aware of events that create uncertainties. Risk assessment and prioritization help choose suitable management actions. Decision and implementation involve executing internal or shared network actions to manage risks. Risk monitoring is necessary as companies and environments change, ensuring continuous risk management.

Supply chains have become more complex and consequently more vulnerable to disruptions due to factors like natural hazards, global outsourcing, and shorter product life cycles (Ivanov and Dolgui 2021; Browning et al. 2023). To reduce vulnerability, resilience is crucial. Recent studies define resilience as redundancy and flexibility (Ivanov et al. 2019). Redundancy involves having extra resources like additional stock, capacity, and suppliers to provide emergency cover. Flexibility involves building capabilities to respond quickly to disruptions and adapt to changing market conditions.

According to Ivanov et al. (2019), enhancing end-to-end supply chain visibility significantly mitigates risks and boosts confidence. A key aspect of this improvement is the sharing of information among supply chain actors, which reduces uncertainty and decreases the need for safety stock. This increased visibility transforms the supply chain to be more responsive and demand-driven. Additionally, effective visibility requires control over operations to enable timely adjustments.

The literature on SCRM underscores the critical importance of identifying, assessing, and mitigating risks to enhance supply chain resilience. Despite various proposed frameworks and strategies, there is a notable gap in developing industry-specific frameworks that effectively integrate both qualitative and quantitative. This study addresses this gap by developing a comprehensive SCRM framework for the hearing care industry, utilizing both quantitative and qualitative methodologies. Following literature guidelines provided by de Oliveira et al. (2017), the proposed framework emphasizes risk identification, assessment, continuous monitoring, and strategies to enhance resilience, such as inventory pre-allocation, segmentation, robust supplier communication, and end-to-end visibility. The framework is validated through a case study on Alpha, a multinational hearing care retailer, demonstrating its potential effectiveness. This study aims to advance both academic understanding and practical applications in SCRM.

3. Methodology

There has been a notable lack of structured understanding regarding the upstream segment of the supply chain, especially in specific industries such as hearing care. To address this gap, we propose a comprehensive risk management framework (see Figure 1) to analyse Alpha's upstream supply chain, identify and prioritize risks, assess suppliers' stockout coping capabilities, assess forecasting accuracy of Alpha, and develop a stockout prevention process. This framework comprises five sequential phases: supply chain mapping, risk investigation, risk prioritization, risk measurement and threshold definition, and business continuity and monitoring (Hallikas et al. 2004; De Oliveira et al. 2017).

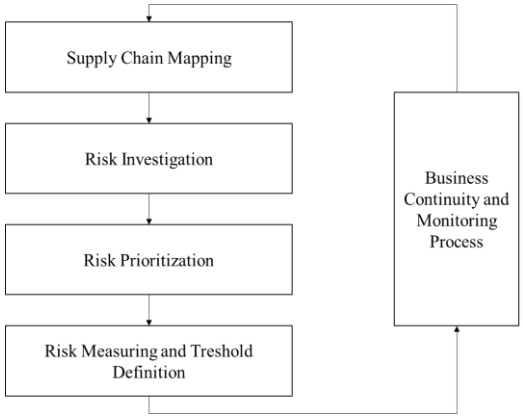

Figure 1: Representation of the framework designed to manage the supply chain risks (adapted from Hallikas et al. 2004 and De Oliveira et al. 2017)

The construction of the SCRM framework involved both data collection and data integration. Data collection consisted of unstructured interviews with supply chain stakeholders from various domains, including supply chain, procurement, quality assurance, monitoring, and information technology. In addition, structured surveys were sent to Alpha's suppliers to gather necessary data on the suppliers' downstream supply chains, including decoupling points, transportation modes, lead times, and stock coverage across countries. Following data collection, the data was compiled and organized into a centralized database for further analysis. This database provided crucial input for subsequent phases of the risk management framework.

The implementation of the SCRM framework (see Figure 1) followed a structured five-phase process. The first phase, Supply Chain Mapping, aimed to gain a comprehensive view of the supply chain and identify visibility gaps. Detailed information on product flow, procurement responsibilities, and logistics indicators was gathered through unstructured interviews with key supply chain personnel. Supply chain mapping was obtained, highlighting key nodes and flow paths, such as production sites, logistics hubs, distribution centres, and the retailer, facilitating the identification of potential risk points and understanding the overall supply chain structure.

The second phase, Risk Investigation, aimed to identify potential risks within the segmented supply chain components. The supply chain was divided into distinct

segments, such as production sites, logistics hubs, and distribution centers. Risks for each segment were identified using risk checklists, brainstorming sessions with supply chain managers and risk management specialists, and analysis of historical supply chain performance data and past incident reports. Historical data provided insights into past occurrences and trends, while expert input helped recognize and understand new and emerging risks. Identified risks were documented in a risk register, categorizing them by source (environmental, network, or organizational) and impact (disruption or deviation).

The third phase, Risk Prioritization, aimed to prioritize identified risks based on their importance and urgency. A team of supply chain experts, including managers and risk analysts, assigned scores to each risk based on its potential impact and likelihood of occurrence. An Eisenhower Matrix (Bratterud et al. 2020), with the dimensions "Important" and "Urgent", was then applied to categorize and prioritize risks, determining the order in which they should be addressed.

The fourth phase, Risk Measuring and Threshold Definition, involved assessing supplier resilience across different regions and managing disruptions at distribution centers (DCs) and production sites (PSs). At Alpha, we used Mean Absolute Percentage Error (MAPE) for demand forecast accuracy and Coefficient of Variation of Error (CVE) for demand variability. We created a Supplier-Country matrix by collecting data on suppliers' operations, conducting qualitative and quantitative risk assessments, mapping suppliers to countries, and assigning risk scores reflecting operational and geographic resilience. Higher-risk countries received more conservative thresholds to maintain adequate stock levels and minimize disruptions. These thresholds informed the stockout prevention process, guiding mitigation actions. The matrix provided a visual and analytical tool to help decision-makers ensure a resilient supply chain.

The objective of the fifth phase, Business Continuity and Monitoring, was to ensure continuous risk monitoring and maintain business continuity. To achieve this, we proposed a stockout prevention process designed for the early detection of potential disruptions and effective mitigation. Regular monitoring and review processes, including usual monitoring, daily monitoring, escalation, order issuance, and mitigation planning, were proposed to track risks and ensure timely responses. Designed for continuous updates based on new insights and changes, these processes ensure supply chain resilience and responsiveness.

Key factors used in designing the stockout prevention process include Quantity in Delay (Q_D) and tolerance quantities. Q_D represents the maximum delay each country can endure before facing a stockout, calculated through detailed supply chain mapping. Tolerance quantities, specifically the Threshold Quantity for Daily Monitoring and the Threshold Quantity for Escalation, are derived from safety stock levels, average daily demand, and lead times. These tolerance quantities trigger monitoring and escalation processes, with higher tolerance for countries with central warehouses (CWs). Suppliers are responsible for monitoring delays, ensuring timely responses to potential risks and maintaining business continuity.

This five-phase methodology is designed to effectively identify, prioritize, and mitigate supply chain risks, aiming to enhance Alpha's supply chain resilience and setting the stage for subsequent analysis and results.

4. Case study

The focus of this study is a hearing aid device, which Alpha, a multinational retailer specializing in hearing care products, procures from its network of suppliers. Subsequently, Alpha dispenses these devices to its clientele in accordance with their individual requirements and preferences.

The market served by Alpha is composed of two main regions: Europe, the Middle East, and Africa (EMEA), and Asia-Pacific (APAC). Each region corresponds to a business area responsible for pursuing Alpha's strategy at the local level and for sharing its business know-how among the constituent countries. The ordering processes work similarly in both regions and are based on Alpha's guidelines. Therefore, the study can be conducted in parallel, with the same assumptions about processes and distribution strategies.

As a retailer, Alpha's operational success hinges significantly on the capabilities of its suppliers to fulfil demand, encompassing both production capacities and logistical proficiency in reaching target markets. To this end, Alpha collaborates with four primary suppliers specializing in hearing aids devices. These suppliers boast a global presence and possess the capacity to meet Alpha's demand on a worldwide scale.

The decisions made by Alpha do not directly impact the operations or processes within the distribution network of its suppliers in the event of a disruption. Consequently, it is incumbent upon the suppliers themselves to undertake the necessary measures for mitigating any adverse effects. To support this, a comprehensive five-phase SCRM framework (Figure 1) was applied to Alpha's supply chain. This framework enabled Alpha to effectively identify and prioritize risks, monitor inventory levels, lead times, and supplier performance. The following subsections detail the specific outcomes of this application, highlighting how the framework is designed to enhance supply chain resilience and prevent stockouts.

5. Results

In this section, we present the results of the application of the proposed SCRM framework (Figure 1) to Alpha's supply chain. This comprehensive framework was implemented to identify, prioritize, and manage risks across different segments of the supply chain, ensuring enhanced operational resilience and efficiency.

The analysis began with understanding how products are stocked in the distribution center based on demand forecasts provided by the retailer. To mitigate the risk of obsolescence, this inventory is pre-allocated to specific

countries. Additionally, we examined the primary routes utilized by suppliers to reach the destinations, which include Asia-Europe air route, Southeast Asia-Australia (SEA-AU) route, and domestic European routes.

Alpha's supply chain was segmented into Production Site (PS), Line Haul (LH), Distribution Centre (DC), Last Mile (LM), and Border of Direct Influence (BOI), aiding in identifying upstream risks classified as environmental, organizational, and network risks (see Figure 2). The Line Haul (LH) segment was further divided into Primary Carriage (PC) and Outbound Carriage (OC). To make risk identification more effective, we combined the classification of risk sources with these supply chain segments. This approach helped us identify where each risk originates and whether it causes minor deviations or major disruptions in the supply chain. The various risks identified for the three categories are: (i) Environmental: LH & LM transportation fluctuation (dev), LH and LM cost of fuel (dev), LH disruption (disr); (ii) Network: LH transportation delays (dev), LH transportation fault (disr); (iii) Organizational: PS production fluctuation (dev), Retailer forecast accuracy (dev), DC inventory coverage fluctuation (dev), PS disruption (disr), DC disruption (disr). (Dev: deviation; Disr: disruption)

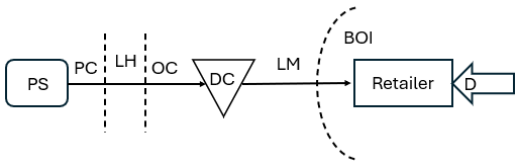

Figure 2: Segmentation of Alpha's supply chain

In the third phase, identified risks were prioritized using an Eisenhower Matrix. High-priority risks, identified in the quadrant High Importance & High Urgency, are inventory coverage fluctuation, production site disruption, distribution center disruption, and forecast accuracy. Focusing on these high-priority risks allows the company to allocate resources effectively and address the most critical issues first. This approach helps in maintaining business continuity, avoiding significant disruptions, and ensuring that strategic goals are not compromised.

In the fourth phase, we quantified risk levels for high-priority risks and defined acceptable thresholds. This included assessing each supplier's resilience to disruptions at distribution centers (DCs) and production sites (PSs). Internal risk analyses at Alpha using MAPE and CVE identified regions with high variability and highlighted where additional inventory buffers were necessary.

We developed a Supplier-Country matrix to evaluate risks and capabilities of suppliers across different countries. This matrix, combining Alpha's internal risk analysis data with supplier-country data, assigned comprehensive risk scores reflecting both operational resilience and geographic risks. Each cell in the matrix indicates vulnerability levels: less than 2 (high vulnerability/stockout risk), 2 to 4 (moderate vulnerability), and greater than 4 (low vulnerability).

Table 1: Final evaluation, risk exposure for country-supplier pairs

Country	Supplier 1	Supplier 2	Supplier 3	Supplier 4
1	4.4	1.35	3.23	1.9
2	4.7	2.01	3.89	2.56
3	2.9	1.18	1.8	N/A
4	4.12	1.43	3.31	1.98
5	4.83	3.09	3.71	4.04
6	5.88	N/A	5.07	3.74
7	N/A	N/A	N/A	N/A
8	3.67	0.98	2.86	1.53
9	4.97	2.29	4.16	2.84
10	4.99	2.3	4.18	N/A
11	6.04	N/A	5.23	N/A

The matrix supported decision-making for the stockout prevention process, identifying countries at risk of stockouts.

Supplier Performance and Risk Exposure, the results highlighted several verified delays. Supplier 2 faced significant delivery issues with Countries 1, 2, and 8. Supplier 1 had the smoothest supply process, indicated by the highest number of cells with values greater than 4, attributed to a strong relationship with Alpha. Supplier 3 had low risk exposure in Country 11 but showed ineffectiveness in Country 3. Supplier 4 faced supply issues with Country 4 due to shortages during the investigation period. Supplier 2 had the highest number of cells with values less than 4, indicating a higher vulnerability to stockouts. This suggests that Supplier 2 has fewer facilities or less capacity compared to other suppliers, resulting in lower resilience in their supply chain.

Using the risk scores from the matrix, Alpha could prioritize which countries required immediate attention to prevent stockouts. While the matrix provided a detailed assessment of supplier risks and capabilities, the defined thresholds will be utilized in the next phase to implement specific mitigation strategies and ensure supply chain resilience.

The fifth phase results in a stockout prevention process ensuring continuous risk monitoring and business continuity. This process identifies potential issues, determines the affected supplier and country, and ensures inventory levels exceed the time needed to restore normal operations. If this condition is not met, an alternative method is identified; otherwise, monitoring continues uninterrupted.

The stockout prevention process specifies threshold percentages of quantities in delay, which trigger three levels of mitigation counteractions: (i) Daily Monitoring Threshold: Triggered at 20% of Quantity in Delay (Q_D) for countries without a central warehouse (CW) and 25% for countries with a CW. This involves daily information exchange to estimate recovery time; (ii) Escalation Quantity Threshold: Triggered at 50% of Q_D for countries without a CW and 70% for countries with a CW. This engages upper management to identify and implement recovery methods; (iii) Critical Escalation Threshold:

Triggered when a supplier declares no coverage available, prompting escalation to the top-level management of Alpha to intervene in the supply chain.

These thresholds ensure a structured approach to risk mitigation, facilitating timely and effective responses to potential disruptions. Designed for continuous updates, these processes ensure the supply chain remains resilient and responsive.

The iterative nature of the framework allows it to flow from the fifth phase back to the first, improving with increased learning over time. This section highlights the outcomes of applying the five-phase SCRM framework to Alpha's supply chain, with significant results in the fourth phase leading to the supplier-country matrix and the fifth phase proposing the stockout prevention process with mitigation counteractions.

6. Conclusions

This study developed a comprehensive five-phase SCRM framework and applied it to a multinational retailer specializing in hearing care products. The framework effectively identifies and prioritizes supply chain risks, evaluates supplier resilience against stockout risks, and proposes measures to mitigate stockouts through defined thresholds and continuous monitoring processes.

In response to the first research question about developing a comprehensive SCRM framework, the primary contributions include the creation of a structured framework that involves supply chain mapping to identify key nodes and potential risk points, risk investigation to categorize risks by source and impact using checklists and historical data, and risk prioritization using the Eisenhower matrix to address critical risks first. Additionally, it includes risk measuring and threshold definition using MAPE and CVE to quantify risks and set thresholds, and business continuity and monitoring processes for ongoing assessment of inventory levels, lead times, and supplier performance. The framework, constructed using best practices, historical data, and expert judgment, ensures robust risk assessment and monitoring of inventory levels, lead times, and supplier performance. The case study validated its effectiveness, highlighting the importance of real-time monitoring, effective threshold setting, enhanced supplier collaboration, and practical methods for assessing supplier resilience.

Regarding the second research question on the practical impacts of the SCRM framework, implementing it in Alpha's supply chain provides several key benefits. Consistent monitoring of safety stock levels would ensure adequate inventory to meet unexpected demand spikes or delays. Robust communication with suppliers would facilitate timely sharing of information, enabling early risk identification and swift resolution. The quantitative risk assessment using MAPE and CVE is expected to provide precise insights into demand forecast variability and supply chain performance, allowing Alpha to make informed decisions and effectively manage risks. These proposed strategies aim to enhance the resilience of Alpha's supply chain, demonstrating the practical effectiveness of the SCRM framework in a real-world context.

The implementation of this SCRM framework provides managers with a structured approach to managing supply chain risks. Managerial implications include the development of proactive risk management strategies, the establishment of robust supplier communication protocols, and the implementation of continuous monitoring systems. These practices enhance operational resilience and help mitigate supply chain disruptions by enabling informed decision-making and timely responses to potential risks.

This study has its limitations. It focuses on physical supply chain risks, excluding informational and financial flows, and is specific to the hearing care industry, affecting generalizability. The accuracy of the framework depends on the quality of supplier data, which can affect risk assessments if the data is inconsistent. Additionally, the study does not explore advanced technologies like AI, blockchain, and IoT, which could enhance the framework's capabilities. These limitations suggest areas for further research to improve understanding of the field of supply chain risks management.

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