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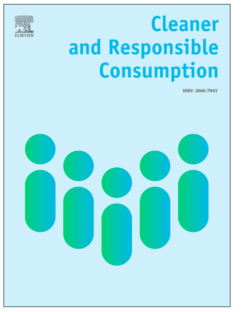

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Title: SUPPLY CHAIN DISRUPTION INDICATORS: VULNERABILITY AND RESILIENCE IN THE GARMENT INDUSTRY IN VIETNAM

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SUPPLY CHAIN DISRUPTION INDICATORS: VULNERABILITY AND RESILIENCE IN THE GARMENT INDUSTRY IN VIETNAM

Abstract

This study contributes to identifying supply chain disruption indicators and resilience strategies, with the aim of enhancing issues related to disruption in the garment industry. Supply chain disruption influences a series of problems, including transportation delays, delivery times slow down and cost increases, etc. Additionally, resilience strategies mitigate and enable a supply chain to respond to disruption while recovering or improving so that risks are reduced, and operations are more efficient. However, previous studies have failed to identify supply chain disruption indicators, construct a hierarchical framework with causal interrelationships among the attributes, and develop resilience strategies to handle disruption situations, especially in the garment industry. This study proposes the creation of 6 aspects and 18 criteria of supply chain disruption and resilience strategy attributes via the fuzzy Delphi method and fuzzy decision-making trial and evaluation laboratory method. The findings show that the causal group consists of supply risk, flexible business strategies and collaborative strategies, whereas the effect group consists of human issues, transportation failure and preventive resilience strategies. In practice, managers should focus on resilience strategies such as backup suppliers, risk and revenue sharing, risk management culture, partnership management, and cooperation with stakeholders to enhance supply chain disruption. This study contributes to synthesize indicators related to supply chain disruption and resilience strategies for adapting and responding to disturbances during disruptions with minimal impacts on performance and future sustainability in the garment industry.

Keywords: Supply chain disruption, Resilience, Vulnerability, Garment industry, Fuzzy Delphi method, Fuzzy decision-making trial and evaluation laboratory

SUPPLY CHAIN DISRUPTION INDICATORS: VULNERABILITY AND RESILIENCE IN THE GARMENT INDUSTRY IN VIETNAM

1. Introduction

The garment industry in Vietnam plays a significant role in the nation's economy, representing approximately 12–16% of the country's overall export earnings. However, the garment industry is now facing several issues because it heavily relies on imported materials from other nations, which leads to delays and interruptions in the supply chain (Ministry of Industry and Trade, 2023). Hence, supply chains must be flexible and resilience strategies can improve supply chain disruptions. Resilience strategies are specifically designed to mitigate the effects of supply chain disruptions and enable a supply chain to respond to a disturbance and better preparedness reduces the impact of supply chain disruptions and improves overall operations. (Shekarian & Mellat, 2021). Zamani et al. (2023) stated that resilience strategies refer to the tactics used to effectively manage risks, uncertainties, and interruptions that may arise from suppliers or other business processes and supply chain integration mechanisms. In addition, aspects such as agility, visibility, forecasting, inventory management, adaptability, cooperation, collaboration, information sharing, and multisourcing are essential components of resilience strategies (Islam et al., 2023). However, previous studies on how supply chain disruptions can be reduced by considering various resilience strategies, such as collaboration, flexibility, redundancy, and agility, are limited; additionally, there has been a limited focus on the relationship between resilience and sustainability (Ivanov, 2022; Al Naimi et al., 2022; Bag et al., 2023). Carissimi et al. (2023) claimed that there is still a lack of scrutiny of the decisions made by companies in selecting the adopted resilience strategies, which encourages companies to reevaluate their managerial decisions in light of the ongoing evolution of their operating environment. Moreover, the assessment of interruptions in certain supply chains, particularly the garment supply chain, is still not given sufficient attention (Canwat, 2024). Therefore, this study aims to fill these gaps by constructing valid attributes related to supply chain disruption and resilience strategies in the garment industry.

Supply risk refers to the possibility of variations in the arrival of supplies in terms of timeliness, quality, and quantity, as well as disruptions to the movement of items and information throughout the network, specifically before they reach the focal companies (Shekarian & Mellat, 2021). However, human issues are the primary catalysts for disruptions in the supply chain, which include factors or impacts that stem from human activities, choices, behaviors, or interventions and significantly affect different areas of the supply chain (Ali et al., 2021). Um & Han (2021) argued that recognizing supply risk as a primary factor in disruptions enables the implementation of flexible resilience solutions in supply networks, which can reduce costs related to managing many suppliers and enhance supplier relationships. Furthermore, transportation failure is characterized by inadequate coordination among supply chain partners and insufficient transportation capacity. Such failure, in turn, has a negative effect on lead time, the product life cycle, consumer demand, inventories, and shortages, resulting in inefficiencies within the supply chain (Dohale et al., 2022). To address these challenges, collaborative strategies involve autonomous firms working closely together to plan and execute supply chain operations to achieve common goals and mutual benefits, which can include partnering for collaborative research or collective process innovation to generate new knowledge and improve the ability to respond effectively to supply chain disruptions (Dohale et al., 2022). Implementing flexible business strategies to manage demand, supply, and process risks may enhance the efficacy of mitigating and controlling supply chain disruptions while also enhancing the resilience of the supply chain (Rajesh, 2021; Piprani et al., 2022).Preventive resilience strategies provide solutions that aim to mitigate the likelihood of supply interruptions, hence decreasing the future impact on supply chain responsiveness and minimizing the costs associated with recovery (Lou et al., 2024; Canwat, 2024). Hence, this study proposes a valid set of attributes of supply chain disruption and resilience strategies, a hierarchical structure is constructed through linguistic references.

Prior research has made efforts to address worldwide disruptions in supply chains, although there is a shortage of studies that specifically target certain supply chains, such as the garment industry. In addition, strategies that aim to increase supply chain resilience after disruptive events are lacking, leading enterprises to be uncertain when their own recovery plans are adopted. Hence, this study identifies valid indicators of supply chain disruption and resilience strategies to propose solutions for overcoming disruption in the context of the garment industry. Additionally, this study uses the fuzzy Delphi method (FDM) to determine quality on the basis of qualitative data and linguistic preferences (Tseng et al., 2022). To establish the interrelationships between attributes, cause–and–effect relationships are modeled via fuzzy decision-making trial and evaluation laboratory (FDEMATEL) for analysis (Bui et al., 2024). As a result, the following objectives are pursued during this investigation:

- To construct a valid set of attributes of supply chain disruption and resilience strategies, a hierarchical structure is constructed through linguistic references.
- To identify the causal interrelationships between the attributes of supply chain disruption and resilience strategies.
- To identify the important attributes of supply chain disruption to increase the resilience of the supply chain in the garment industry context.

This study contributes to the literature in both theoretical and practical implications, which are as follows: (1) construct a valid set of attributes of supply chain disruption and resilience strategies, (2) visualize the causal interrelationships between attributes and (3) indicate important practical directions to enhance supply chain disruption in the garment industry in the context of Vietnam. This study synthesizes indicators related to supply chain disruption and resilience strategies for adapting and responding to disturbances during disruptions with minimal impacts on performance and future sustainability in the garment industry.

This study is divided into six sections. The first part of the paper sets the stage for the investigation by discussing relevant earlier studies and providing the necessary context. In Section 2, a literature review on supply chain disruption and resilience strategies, including the proposed method and measures, is presented. The third section explains the FDM and FDEMATEL method utilized in this study. In Section 4, the results are presented. In Section 5, the theoretical and practical implications are examined. The last section summarizes the study's conclusions, limitations, and recommendations for further research.

2. Literature review

2.1. Supply chain disruption

The mitigation of supply chain disruptions has attracted significant attention in both the academic and industrial sectors. Supply chain disruptions may occur due to significant natural disasters, severe weather conditions, wars and political instability, export/import limitations, terrorism, economic downturns, delays in information and communications, and/or breakdowns in transport infrastructure (Zhang et al., 2024). In addition, supply chain disruption encompasses the vulnerability and disruption of the supply chain process caused by unknown events, resulting in adverse effects on the productivity, product quality, and delivery capacity of the whole supply chain (Song et al., 2024). Lou et al. (2024) argued that supply chain disruption has a prolonged impact on downstream enterprises and the whole supply chain, causing a ripple effect across the entire supply chain. Supply chain disruptions can occur within organizations (internal disruptions), as well as on the supply side (supply-side disruptions) and customer side (customer-side disruptions) of the supply chain. These disruptions can have various negative effects, such as increased costs, higher prices, and longer delivery times (Canwat, 2024; Dou et al., 2024). The literature has placed significant emphasis on the problem of supply chain interruption; however, this subject poses a growing challenge to the supply chain of products and companies at its core. Supply chains have become highly intricate and interconnected, and any disruptions can trigger a chain reaction with severe repercussions for all levels of the supply chain (Katsaliaki et al, 2022; Al Naimi et al., 2024). Therefore, this study aims to contribute to the literature by exploring the indicators of supply chain disruption in a specific supply chain to propose strategies that enhance the supply chain in a disruptive context.

The primary emphasis of disruption events on industrial supply chains lies in the supply process, internal operations, and demand side of the three linkages; the key actors are suppliers, manufacturers, and customers (Aldrighetti et al., 2023). Ali et al. (2021) argued that enterprises are facing a growing risk of supply chain disruptions in the current competitive and unpredictable business climate. Can Saglam et al. (2021) stated that disruptions and disturbances in the supply chain might result in competitive disadvantages for businesses and hinder the achievement of their supply chain goals. Therefore, implementing effective supply chain disruption management is crucial for enhancing supply chain performance; simultaneously, mitigating supply chain disruptions is a primary concern for organizations globally (Ali et al., 2021). Um & Han (2021) reported that, owing to the recognition of disruptions as unavoidable occurrences in the current turbulent global business environment, organizations have attempted to reduce certain risks through conventional supply chain risk management techniques, such as interpretive structural modeling, fault tree analysis, and event tree analysis. In addition, firms must establish disruption recovery procedures to address any future supply chain disruptions or crises effectively to ensure that their production demand is adaptable to handle fluctuations in demand resulting from unexpected supply network disruptions (Islam et al., 2023). However, most of the studies have not explicitly referred to each type of supply chain disruption; in addition, companies find it difficult to measure the effects of supply chain disruptions, and empirical evidence remains limited (Shekarian & Mellat, 2021; Katsaliaki et al, 2022). Furthermore, while disruptions are inevitable, organizations can minimize the impact of disruptions by using conventional supply chain strategies; however, they are unable to eliminate all disruptions (Duong & Chong, 2020). Hence, the objective of this research is to determine accurate characteristics of supply chain interruption and effective techniques for managing such disruptions. These findings may greatly benefit organizations in their practical implementation.

2.2. Resilience strategies

The resilience of a supply chain refers to its capacity to effectively recover from unforeseen occurrences and return to a normal or improved condition, despite the many dangers posed by supply chain disruptions. Lou et al. (2024) proposed that resilience is a capacity that enables a supply chain system to rapidly recover from a disruption or to attain a more advantageous condition. Resilience refers to the capacity of the supply chain to effectively anticipate, adapt to, persevere through, and rapidly react to unforeseen occurrences (Katsaliaki et al., 2022; Islam et al., 2023; Lou et al., 2024). Duong & Chong (2020) argued that resilience enables supply chains to increase their ability to anticipate, mitigate, and swiftly recover from disruptions. Resilience is also often defined in the literature as the capacity to reduce vulnerability, quickly recover, maintain sustainability, achieve performance growth, respond effectively, and build new skills and opportunities in a tough environment (Saad et al., 2021; Um & Han, 2021; Canwat, 2024). Moreover, resilience, in this context, is the ongoing ability to anticipate, adapt, and thrive in the presence of various shocks and enhances the capacity to initiate change before it becomes urgently necessary (Saad et al., 2021). Resilience is a demonstrated solution for addressing supply chain disruption and vulnerability. It may be attained via a diverse range of tactics, which include engaging in activities to decrease the probability of risks and mitigate their adverse consequences (Carissimi et al., 2023). To handle supply chain disruptions efficiently, companies must use several resilience methods in the face of unpredictable supply and demand conditions.

The capacity of the supply chain needs to be increased to withstand disruptions and recover quickly, which requires the implementation of a range of resilience strategies (Alikhani et al., 2023). Supply chain resilience can be enhanced by many strategies, which fall into three major categories: preventive, concurrent and reactive strategies. Preventive strategies focus on the supply chain and are implemented before disruptions occur. Concurrent strategies involve quick thinking and immediate responses to handle disturbances. Reactive strategies aim to mitigate outsourcing risks and recover from disruptions by returning to the original or desired state (Can Saglam et al., 2021; Alikhani et al., 2023; Canwat, 2024). In addition, the implementation of resilience strategies in the early stages of the supply chain as a reaction to a disruptive event may significantly impact the selection and efficacy of resilience methods by downstream entities (Alikhani et al., 2023). According to Duong & Chong (2020), organizations attempt to minimize the impact of interruptions by using conventional supply chain methods, but they are unable to prevent all disruptions. Furthermore, the significance of supply chain resilience is immense; however, on the basis of the authors' understanding, the existing research does not establish a connection between disruptions and the specific practices that enhance supply chain performance (Al Naimi et al., 2022; Alikhani et al., 2023). Numerous previous studies have not specifically mentioned each type of supply chain disruption when investigating the impact of resilience enhancers on managing supply chain disruption (Shekarian & Mellat, 2021). Thus, the current research aims to examine a valid set of indicators for supply chain disruption and resilience strategies, as well as the interrelationship between these indicators, to enhance the performance of company supply chains in the context of disruptions.

2.3. Indicators of supply chain disruption and resilience strategies

In the previous literature, the examination of supply risk provides an established set of scholarly contributions on supply chain disruptions. Song et al. (2024) argued that supply risk is a negative impact resulting from a breakdown in the quality, quantity, or timeliness of raw materials provided by the upstream segment of the supply chain. Supply risk refers to the possibility of variations in the delivery of supplies in terms of timeliness, quality, and quantity, as well as disruptions to the movement of items and information across the network, specifically before they reach the focal companies (Shekarian & Mellat, 2021). Supply risk can be described as the probability of a supply interruption that might lead to shortages and, consequently, sharp price hikes (Van den Brink et al., 2020). Supply risk may arise when companies request more materials from their regular or main suppliers to obtain emergency supplies, modify the predetermined supply amounts, or negotiate price adjustments for the supplied commodities (Aldrighetti et al., 2021). Notably, supplier-driven risk can hinder a manufacturing company's ability to operate and affect the development of the supply chain's resilience. These risks include delivery problems, lengthy lead times, and unreliability, which can cause disruptions both upstream and downstream (Piprani et al., 2022). For that reason, practitioners and scholars stress that to compete in today's tumultuous and unpredictable economy, companies must have the capability and strategies to effectively manage risk in supply and disruption in that supply chain.

Rather than focusing on supply–demand coordination events, processing challenges are more focused on supply–demand coordination events, which may be the consequence of insufficient or failing procedures, control, people, or systems. Shekarian & Mellat (2021) argued that processing challenges refer to situations where there may be deviations from achieving the target quality and quantity within the specified timeframe. This category of risk encompasses hazards related to the quality, timeliness, and capacity of in-bound and out-bound logistics, as well as in-house activities. Moreover, these challenges are connected to the disturbance of assets held domestically and the dependability of the supporting communication system, transportation system, and infrastructures. Few studies have investigated the management of processing issues to address supply chain disruption by using resilience capabilities and supply chain strategies (Um & Han, 2021). Therefore, it is essential to examine the processing difficulties that might lead to disruptions in the supply chain and implement resilience methods to address these obstacles effectively.

Human resources are crucial for firms to withstand upheavals and are also a growing problem for corporations (Saad et al., 2021). However, human issues are factors or effects arising from human activities, choices, behaviors, or interventions that affect different components of the supply chain (Ali et al., 2021). Disruption events are a specific type of event that may occur as a result of intentional or unintentional human actions, such as war, terrorist attacks, epidemics/pandemics, and strikes. This type of problem is typically characterized by a high magnitude of consequence and a low likelihood of occurrence (Aldrighetti et al., 2021; Piprani et al., 2022). In addition, human issues include several components, such as perception, cognition, physicality, and psychosocial variables, in the workplace. These factors present significant challenges and may impact output by increasing the likelihood of mistakes or workplace abuse (Sgarbossa et al., 2020). Saad et al. (2021) highlighted that the interconnected and exacerbating obstacles associated with human factors increase the susceptibility of organizations to failure. In addition, there is a lack of consideration of human factors and their influence on system and employee performance. This lack results in inaccurate planning outcomes and decisions, underperforming systems, and heightened health risks for employees. These factors can directly impact the performance of the supply chain and easily lead to disruptions (Sgarbossa et al., 2020).

Transport failure is a significant indicator resulting from an enormous disruption that leads to a delay or halt in the movement of goods and services. This disruption can be caused by natural disasters, heightened threat levels, political and economic instability, or vehicle accidents, which can pose substantial difficulties for companies (Fartaj et al., 2020). In addition, the failure of transportation may result in disruption of the supply chain due to various hidden expenses, such as delays in transportation, extended lead times, and changes in tariffs and customs regulations (Handfield et al., 2020). The failure of transportation is also associated with inadequate port infrastructure, limited warehouse space, subpar freight transportation infrastructure, a lack of accessible and high-quality transshipment infrastructure, and outdated transport and handling equipment and vehicles (Liu et al., 2023). Moreover, infrequent but devastating natural calamities, such as fires, hurricanes, floods, storms, earthquakes, and landslides, have the potential to affect transportation routes and result in substantial shipping delays, leading to disruptions (Fartaj et al., 2020). An examination of transportation failures in supply chains is crucial for reducing disruptions and preventing harm to products. However, there is limited availability of academic and practical research specifically dedicated to analyzing transportation failures in the supply chain (Fartaj et al., 2020; Liu et al., 2023). Therefore, this research aims to uncover the significant elements that contribute to transportation failure, which might have a direct influence on disrupting the supply chain.

Collaboration is a kind of interaction that occurs among individuals who agree to pool their resources and make joint choices to address issues, accomplish shared objectives, fulfill social obligations, and obtain benefits (Shekarian & Mellat, 2021; Yan et al., 2023). Duong & Chong (2020) emphasized that collaborative strategies play a crucial role in enhancing the resilience and capabilities of organizations to effectively coordinate and carry out supply chain activities in pursuit of shared objectives. According to Al Naimi et al. (2022), collaborative strategies are defined as the capacity of organizations or supply chains to cooperate efficiently and promptly address supply chain disruptions with partners and other entities within the supply chain. Prior research has investigated the correlation between collaborative tactics and supply chain resilience, revealing a favorable association between collaboration and supply chain resilience (Duong & Chong, 2020; Can Saglam et al., 2021). Collaborative strategies are implemented by sharing information, increasing visibility, promoting transparency, and forming partnerships across the supply chain. These initiatives aim to increase the ability of the supply chain to reduce disruptions, respond to risk events, and recover from disruptions (Carissimi et al., 2023). Additionally, implementing improved collaborative strategies can effectively utilize the capabilities of different functional departments within the supply chain. This can enhance pricing capabilities, offer more options for postponement, and enable businesses to respond quickly and effectively to unexpected disruptions (Dohale et al., 2022; Liu et al., 2023).

There has been a growing emphasis on enhancing supply chain resilience, especially preventive resilience strategies, to mitigate the impact of environmental unpredictability and minimize the consequences of supply chain disruptions (Al Naimi et al., 2022). Canwat (2024) noted that preventive resilience strategies refer to the measures taken before a disruption occurs, which include planning, predicting, alerting, and preparing for the disruption. Preventive resilience strategies possess carefully crafted capabilities that allow the supply chain to decrease the likelihood of disruptive events or minimize their effects, ultimately leading the business toward a more robust and enduring state (Al Naimi et al., 2022). To reduce the likelihood of supply disruptions, manufacturing companies prioritize preventive resilience strategies. In practice, manufacturers invest in establishing stable supply relationships with their suppliers or opt for dual-sourcing procurement methods as effective measures to mitigate the risk of supply disruption (Lou et al., 2024). Overall, using preventive resilience strategies has been shown to be beneficial, as it enables managers to assess the actual effectiveness of various initiatives and develop a comprehensive strategy to mitigate the risk of disruptions (Aldrighetti et al., 2021).

Flexibility is a crucial factor for supply networks that function in challenging circumstances and pertain to a company's capacity to adapt to significant and lasting alterations in the supply chain. Flexible business strategies are connected to potential solutions for improving supply chain resilience while also accounting for the need to minimize complexity in supply networks (Rajesh, 2021). Dohale et al. (2022) also highlighted the critical significance of using a flexible business strategy in supply chains to increase resilience and mitigate the negative effects of uncertain disruptive risk occurrences. The concept of a flexible business strategy refers to the capacity of supply chains to adapt promptly to both favorable and unfavorable environmental factors while effectively choosing the most appropriate alternatives and enhancing their resilience to disruptions (Al Naimi et al., 2022; Alikhani et al., 2023). Nevertheless, there is a lack of research investigating the empirical data concerning the impact of flexible business strategies on the development of overall flexibility in supply chains (Rajesh, 2021; Shekarian & Mellat, 2021). According to Mirzaee et al. (2024), including appropriate flexibility measures in a firm has been shown to construct a resilient and environmentally responsible supply chain, underpinned by a diverse set of resilience strategies, and to establish an infrastructure that adeptly handles disruptions while advancing sustainability. Therefore, it is necessary to clearly define the importance of adaptable business strategies in improving the ability of the supply chain to withstand challenges in the current research.

2.4. The proposed methods

Previous studies have used a variety of methodologies to evaluate the efficacy of supply chain disruption and resilience strategies. Ali et al. (2021) utilized the Delphi method and the fuzzy analytic hierarchy process to create a framework for identifying, analyzing, and evaluating supply chain disruption factors and drivers. The authors identified and examined a total of sixteen disruption drivers across four categories: natural, human-made, system accidents, and financial. Moreover, Katsaliaki et al. (2022) employed explicit methodologies and a bibliometric approach to consolidate available data on various types of disruptions, their effects on supply chains, resilience approaches in supply chain design, and recovery strategies that bolster resilience and mitigate disruption risks. Moosavi et al. (2022) also employed a set of current bibliometric, network, and thematic analyses to identify significant contributors, primary research streams, and solutions for managing disruptions in supply chain performance during the COVID-19 pandemic. Al Naimi et al. (2022) utilized the systematic mapping review approach, also known as scoping review, to evaluate the current understanding of supply chain resilience and reconfiguration in the face of disruptions. The authors assessed many aspects, including research sources, study type, geographical region, and methodology. In addition, Lou et al. (2024) utilized the inverse induction method to assess and compare three resilience strategies (investment in a fixed supplier for consistent supply, dual sourcing by adding backup suppliers, and a hybrid strategy). The authors examined the impact of these strategies on enhancing supply chain resilience during supply disruptions and determined the most suitable resilience strategies for manufacturing enterprises operating in complex supply chain environments. However, the cause–and–effect relationship between supply chain disruption and resilience strategies is still unclear because it involves other complicated attributes, as well as other issues and resilience strategies.

This study validates the FDM and FDEMATEL method set of supply chain disruption and resilience strategy attributes while also examining the causal interrelationship between all of these variables. The FDM is employed to eradicate superfluous indicators and validate the proposed structure via the linguistic references of experts (Bui et al., 2024). By resolving perplexing and imprecise judgments made throughout the decision-making process and determining levels of importance, the FDM seeks to reduce unreliable attributes of qualitative data. The FDEMATEL approach is then employed to determine the subjective weights of the indicators, as it provides a more comprehensive explanation of the interrelationships between these attributes (Tseng et al., 2022). For example, Bui et al. (2024) implemented the FDM to identify the appropriate attributes among green manufacturing performance indicators by utilizing qualitative data and linguistic preferences. Tseng et al. (2022) devised and used a hybrid approach that combines the FDM and FDEMATEL to include both subjective and objective weights; this approach was employed to investigate the crucial characteristics of sustainable supply chain management in the context of the seafood industry. The abovementioned proposed methodologies are used in this study to develop a set of trustworthy indicators for measuring the indicators of supply chain disruption and resilience strategies and to determine cause-and-effect relationships between indicators.

2.5. The proposed measures

The attributes of supply chain disruption and resilience strategies identified from the FDM findings are shown in Table 4. A suggested list of valid attributes consists of six elements and 18 criteria. These attributes are supply risk, human issues, transportation failure, collaborative strategies, preventive resilience strategies, and flexible business strategies.

Supply risk (A1) is related to the probability of a supply disruption and pertains to shortages in supply markets (Van den Brink et al., 2020; Sharma et al., 2020). Supply risk measurement indicators include a shortage in supply (C1), which refers to a shortfall in supply and an inadequate quantity of a certain product, material, or resource available to match demand (Panwar et al., 2022). As a result, most enterprises are not equipped to meet the growing demand or supply at new demand locations given their existing production capacity. Moreover, companies see a decline in their usual production levels due to a shortage of both raw materials and people, resulting in significant disruption. In addition, supply cost risk (C2) pertains to the manufacturer relinquishing control over material prices, specifically as a result of relying on a single source, which may lead to disruptions (Rajesh, 2021). An unreliable supplier (C3) reflects that the supplied amount of materials is consistently lower than the predicted quantity (Islam et al., 2022). Financially distressed suppliers (C4) face substantial financial challenges or instability. This may lead to supply shortages or disruptions in the delivery of raw materials, ultimately causing delays, shortages, or a decline in income for downstream firms (Wagner et al., 2022).

Processing challenges (A2) are related to the disruption of assets possessed inside an organization and the dependability of the communication system, transportation system, and infrastructures that support them (Shekarian & Mellat, 2021). Technology breakdown (C5) refers to software flaws, hardware problems, and network outages as the primary causes of technology failure in the industrial sector (Shekarian & Mellat, 2021). Machine failure (C6) refers to instances in which machines do not operate smoothly or are not well configured for the specific fabric used in the manufacturing process, which may lead to disruptions (Praharsi et al., 2021). Structural risk (C7), fire risk (C8) and electrical risk (C9) are considered potential dangers or inherent weaknesses in the physical infrastructure, operating procedures, or organizational framework of garment factories; smoke, heat and toxic gases; and potential hazards associated with the use or presence of electricity, which can manifest in many different forms, including electric shock, electric shock, electrical fires and explosions (Maalouf & Hoque, 2022).

Human issues (A3) are relevant to factors or effects that stem from human activities, choices, behaviors, or interventions that affect many facets of the supply chain (Sgarbossa et al., 2020; Ali et al., 2021). The shortage of skilled manpower (C10) in manufacturing factories may be attributed to industry owners reducing expenses, which may result in the dismissal of skilled workers (Paul et al., 2021). Workers suspend production (C11) when manufacturing or production activities are stopped or greatly reduced because of the suspension of workers. This suspension is typically caused by poor working conditions, unsafe factories, low worker salaries, unpaid wages or delayed payments, worker abuse, social welfare issues, and other related problems (Handfield et al., 2020). Moreover, discrimination against female workers (C12) includes instances of verbal abuse, sexual harassment, public humiliation due to failure to fulfill objectives, excessive workload, inadequate remuneration, and compulsory action over time. These issues are prevalent in the garment sector, which is staffed mostly by female workers (Maalouf & Hoque, 2022). Inadequately skilled operators (C13) negatively impact the efficient functioning of supply chains. This is because operators, who are newly appointed and inexperienced in operating machines, lack the necessary knowledge and understanding to handle variations in garment production lines (Fartaj et al., 2020). Moreover, unskilled and inadequate labor may lead to the production of inappropriate, hazardous, mishandled, and defective goods, hence potentially increasing both transportation expenses and the total cost of the product.

Transportation failure (A4) may be linked to issues such as insufficient coordination among supply chain partners, limited transportation capacity, and inadequate infrastructure for roads, highways, railways, airways, harbors, and sea lanes. The lack of transport productive crews (C14) refers to a scenario in which there is an insufficient number of staff available to operate transportation vehicles, such as trucks, ships, trains, or aircraft. This shortage negatively impacts operational efficiency and leads to inefficient and suboptimal work hours (Praharsi et al., 2021). A poor transportation system (C15) leads to inefficiencies in the supply chain by causing delays in the procurement and delivery processes. This, in turn, generates bull-whip effects and impacts the cost of inventory (Fartaj et al., 2020). In addition, the breakdown or failure of machines or equipment associated with the transportation system, such as cranes, fork lifts, roller conveyors, belt conveyors, chains, and ramps, may result in a substantial delay in the movement of goods. The shortage of containers (C16) hampers industrial operations and disrupts supply chains, resulting in unanticipated financial losses for enterprises and prolonged storage of available-to-promise items in warehouses (Praharsi et al., 2021). Wide transportation costs (C17) refer to the escalation of transportation expenses, such as railway haulage charges, hinterland transportation prices, port tariffs, fuel costs, and other related factors, resulting in elevated industry-wide transportation costs, which exert great pressure on building resilience (Liu et al., 2023).

Collaborative strategies (A5) include partnership management (C18), which involves effectively managing partnerships and establishing and maintaining long-term, strategic relationships with suppliers, manufacturers, and other service providers. Such strategies can increase trust, reduce market uncertainty, and facilitate effective adaptation (Liu et al., 2023). Risk and revenue sharing (C19) involves partners working together to identify and address potential hazards in the supply chain, thereby enhancing the competitive advantage of all the partners involved (Al Naimi et al., 2022). Furthermore, cooperation with stakeholders (C20) in the garment business, which involves suppliers, manufacturers, and buyers exchanging expertise, information, risks, and rewards, is a crucial strategic activity (Habib et al., 2022). Market collaborative innovation (C21) is an indicator that refers to the practice of supply chain focal enterprises working with stakeholders to consistently extend the market area, increase marketing channels, and explore prospective needs (Yan et al., 2023). Business–government collaboration (C22), which involves the implementation of supporting policies and regulations by governments on trade and finance, as well as the collaborative development of trade facilitation procedures and the establishment of a joint committee, has the potential to significantly improve trade facilitation (Liu et al., 2023).

Preventive resilience strategies (A6) are robust and enhance durability and anticipate potential disturbances without considering activities taken during the predisruption phase (Aldrighetti et al., 2021). Supply diversification strategies (C23) involve a manufacturer's approach to mitigating the risk of supply interruption by enhancing supplier redundancy, which proves cost-effective for the company (Lou et al., 2024). Quality assurance (C24) refers to the systematic process of creating, manufacturing, evaluating, and analyzing goods to ensure that they satisfy the intended level of quality for the company's target market (Mirtsch et al., 2023). Artificial intelligence technologies (C25) have the potential to efficiently plan, control, and schedule the production of clothing; optimize production processes; improve the quality of a product; develop the right products by quickly extracting customer expectations; sense the market; optimize internal and external supply chains; and stimulate creativity in the workforce by automating business processes (Song et al., 2024). Moreover, risk management culture (C26) plays a crucial role in developing supply chain resilience within organizations. It enables the organization to identify potential risks and enhance the supply chain's ability to mitigate risks and minimize its vulnerability (Al Naimi et al., 2022). Logistics and inventory management (C27) include efficient transportation, storage, and delivery of materials and completed goods while ensuring that the appropriate inventory levels are maintained to fulfill consumer demand without excess or shortages (Islam et al., 2023). Computerized planning system tools (C28) are software tools that assist with the scheduling of operations, timely rescheduling in the event of disruptions, and the retrieval of enterprise data from a single access point. These tools are particularly useful for informed decision-making, especially in emergency interventions (Katsaliaki et al., 2022).

Flexible business strategies (A7) are crucial for supply chains working in various circumstances and may effectively minimize complications while enhancing network resilience (Rajesh, 2021). Innovating production processes (C29) may lead to improvements in efficiency, quality, sustainability, and flexibility, hence mitigating the negative effects of garment manufacturing processes (Islam et al., 2022). Supplier development (C30) reflects the strategic initiatives undertaken by a purchasing organization to improve the skills of its suppliers and optimize the procedures within the supply chain (Maalouf & Hoque, 2022). Digital transformation (C31) has the potential to convert the operations of a garment company into a sustainable business. This transformation can be achieved by closely monitoring and ensuring that suppliers adhere to the brand's principles and policies, as well as by minimizing polluting gas emissions and environmental damage at every step of the supply chain (Song et al., 2024). Just-in-time (JIT) delivery (C32) is a strategy aimed at minimizing inventory levels, reducing waste, and improving quality. Garment manufacturing companies only store essential materials and materials that can be implemented via the JIT method, avoiding long-term inventory holding (Biswas & Sarker, 2020). In addition, the backup supplier (C33) approach involves acquiring supplies from other sources in case of any interruption to production time or yield, thereby ensuring the continuity of production operations (Al Naimi et al., 2022).

3. Methods

3.1. Industrial background

The garment industry in Vietnam has undergone substantial development and has made a major contribution to the country's economic progress. Among all the industrial export items, the garment industry has the largest export turnover and growth rate. Additionally, it is a prominent industry for exporting goods, making a substantial contribution to the country's economic expansion and representing 12–16% of the total export revenue. Garment businesses are currently facing supply chain disruption due to challenges in finding raw material suppliers, which are caused by the unpredictable nature of global commerce. Furthermore, there are high inventory levels, significant decreases in demand for commodities in general and apparel products specifically, and rising costs of raw materials (Ministry of Industry and Trade, 2024). According to the Ministry of Industry and Trade (2023), relying on imported raw materials has negative consequences for both short-term production development and economic growth, as well as long-term impacts on Vietnam's industry and overall economy. Moreover, the garment industry is now facing immediate challenges such as a shrinking market, decreased orders and unit prices, internal obstacles in acquiring capital, rising input costs, logistical issues, and a shortage of labor resources, all of which have resulted in disruptions to the supply chain. To minimize disruption, the garment industry in Vietnam should engage in trade connections with international businesses and become part of the production chain of global garment companies. This involves establishing links at every stage of the value chain, i.e., from producing raw materials and accessories to the final product. Leading brands are also encouraged to collaborate to exchange managerial knowledge and technology, as well as to contribute to the advancement of supplementary and primary materials for the establishment of a local supply network. The industry's supply chain subsequently has the ability to reduce interruptions in the manufacturing process, enhance the value of products, and support the development of the industry in alignment with environmentally friendly and sustainable global trends.

To assist practitioners in navigating and achieving greater levels of operational performance, the current research is carried out with the purpose of identifying supply chain disruption and resilience strategy elements in the fashion industry. In light of this, a group of fifteen experts is formed, consisting of individuals with a significant amount of consulting experience, as well as professionals, researchers, and other specialists.

3.2. Fuzzy Delphi method (FDM)

This research uses a combination of fuzzy set theory and the Delphi method to address the issue of insufficient expert references and enhance the quality of questionnaires (Ishikawa et al., 1993). This method is used to increase the precision of the indicators by including the linguistic references provided by experts. It offers advantages such as decreasing the number of participants and the time it takes to obtain responses while providing an effective evaluation of experts. The fuzzy assessment is transformed into precise numerical values, aided by methods that help reduce the duration of surveys and expenses.

The analytical process starts with expert a scaling the value of indicator b as $j = (x_{ab}; y_{ab}; z_{ab})$, $a = 1,2,3,\dots,n$; $b = 1,2,3,\dots,m$, as j_b is the weight of b presented as $j_b = (x_b; y_b; z_b)$ with $x_b = \min(x_{ab})$, $y_b = (\prod_1^n y_{ab})^{1/n}$, and $z_b = \max(z_{ab})$. Afterward, the linguistic references from experts are transformed into triangular fuzzy numbers (TFNs) (in Table 1).

The convex combination value D_b is calculated by means of a γ cut as follows:

$$u_b = z_b - \gamma(z_b - y_b),\ l_b = x_b - \gamma(y_b - yx_b),\ b = 1,2,3,\dots,m \quad (1)$$

The γ value can be modified from 0 to 1 according to whether experts' perceptions are negative or positive. The value is usually specified as 0.5 in the general scenario.

The D_b is then indicated as follows:

$$D_b = \int(u_b, l_b) = \delta[u_b + (1-\delta)l_b] \quad (2)$$

where δ represents the positive balance of the expert's ultimate assessment.

The threshold to refine the valid indicators is computed as $t = \sum_{a=1}^{n}(D_b/n)$.

Once $D_b \geq t$, indicator b is accepted. If not, it is obligately eliminated.

Table 1. Transformation table of linguistic terms for the FDM.

Linguistic terms (performance/importance)	Corresponding triangular fuzzy numbers (TFNs)
Very high	(0.75, 1.0, 1.0)
High	(0.5, 0.75, 1.0)
Medium	(0.25, 0.5, 0.75)
Low	(0, 0.25, 0.5)
Very low	(0, 0, 0.25)

3.3. Fuzzy decision-making trial and evaluation laboratory (FDEMATEL)

Fuzzy set theory is used to translate human linguistic judgments under uncertainty into quantitative data, whereas DEMATEL is intended to construct causal interrelationships among indicators under complex situations. The method adopts a defuzzification technique to generate the crisp values of the FTNs. The fuzzy membership functions $\tilde{e}_{ij}^{k} = (\tilde{e}_{1ij}^{k}, \tilde{e}_{2ij}^{k}, \tilde{e}_{3ij}^{k})$ are used to calculate the total weighted values. Accordingly, the left and right values are computed via the minimum and maximum fuzzy numbers. The crisp values are then acquired into a total direct relation matrix for diagram mapping to simplify the analytical results. The interrelationship structure comprises specific indicators that denote vital means in the construct. A set of indicators is presented as $F = \{f1, f2, f3, \cdots, fn\}$ to execute pairwise evaluation, creating the mathematical connections.

This study accumulates crisp values via linguistic scales ranging from VL (very low) to VHI (very high) (Table 2). When k experts are included in the evaluation process, $\tilde{e}_{ij}^{k}$ represents the fuzzy weight of indicator i^{th} effects on indicator j^{th} estimated by expert k^{th}.

Table 2. TFN linguistic scale for FDEMATEL.

Scale	Linguistic terms	Corresponding TFNs
1	Very low	(0.0, 0.1, 0.3)
2	Low	(0.1, 0.3, 0.5)
3	Medium	(0.3, 0.5, 0.7)
4	High	(0.5, 0.7, 0.9)
5	Very high	(0.7, 0.9, 1.0)

The fuzzy numbers are abbreviated as follows:

$$F = \left(f\tilde{e}^k_{1ij}, f\tilde{e}^k_{2ij}, f\tilde{e}^k_{3ij}\right) = \left[\frac{(e^k_{1ij} - mine^k_{1ij})}{\Delta}, \frac{(e^k_{2ij} - mine^k_{2ij})}{\Delta}, \frac{(e^k_{3ij} - mine^k_{3ij})}{\Delta}\right] \quad (8)$$

where $\Delta = maxe^k_{3ij} - mine$

The left (lv) and right (rv) normalized values are generated as follows:

$$\left(lv^n_{ij}, rv^n_{ij}\right) = \left[\frac{(fe^k_{2ij}}{\left(1 + fe^k_{2ij} - fe^k_{1ij}\right)}, \frac{fe^k_{3ij}}{\left(1 + fe^k_{3ij} - fe^k_{2ij}\right)}\right] \quad (9)$$

The total normalized crisp value (cv) is computed as follows:

$$cv^k_{ij} = \frac{[lv^k_{ij}\left(1 - lv^k_{ij}\right) + (rv^k_{ij})^2]}{(1 - lv^k_{ij} + rv^k_{ij})} \quad (10)$$

The synthetic values used to accrue individual insight from k respondents are subsequently implemented as follows:

$$\tilde{e}^k_{ij} = \frac{(cv^1_{ij} + cv^2_{ij} + cv^3_{ij} + \cdots + cv^3_{ij})}{k} \quad (11)$$

Consequently, pairwise comparison is used to obtain the direct relation (IM) $n \times n$ initial matrix, where $\tilde{e}^k_{ij}$ is the effective level of indicator i on indicator j, moderated as $IM = [\tilde{e}^k_{ij}]_{n\times n}$.

The normalized direct relation matrix (U) is developed as follows:

$$U = \tau \otimes IM$$
$$\tau = \frac{1}{\max\limits_{1\le i\le k} \sum_{j=1}^{k} \tilde{e}^k_{ij}} \quad (12)$$

The interrelationship matrix (W) is obtained via the following:

$$W = U(I - U)^{-1} \quad (13)$$

where W is $[w_{ij}]_{n\times n}$ $i, j = 1,2,\cdots n$

The values of the driving power (A) and dependence power (B) are summed from the row and column value interrelationships matrix as follows:

$$\mathrm{A} = [\textstyle\sum_{i-1}^{n} w_{ij}]_{n\times n} = [w_i]_{n\times 1} \quad (14)$$

$$\mathrm{B} = [\textstyle\sum_{j-1}^{n} w_{ij}]_{n\times n} = [w_j]_{1\times n} \quad (15)$$

The indicators are placed in an interrelationship diagram obtained from $[(\mathrm{A} + \mathrm{B}), (\mathrm{A} - \mathrm{B})]$, which in turn is organized into horizontal and vertical vectors. The indicators are grouped into causal and effected groups on the basis of positive or negative values of $(\mathrm{A} - \mathrm{B})$. (A + B) represents the indicators' importance; the larger the (A + B) value indicator is, the more important it is. This study uses the average value of (A + B) to classify the top important causal indicators that need to be focused on.

4. Results

This section provides a concise overview of the findings from the FDM and FDEMATEL investigations. It provides a comprehensive framework for understanding the hierarchical structure of supply chain disruption and resilience methods, as well as the causal interrelationships between different aspects.

4.1. Fuzzy Delphi method results

The current research develops a total of 33 criteria, which are derived from seven distinct aspects of the hierarchical model. Table 3 displays the results, including the weight and threshold of each feature, to assist in narrowing the list of qualifying attributes. The FDM is employed to refine the valid attributes via Equations (1) and (2), with a threshold value of 0.621, as shown in

Table 3. Table 4 shows that 18 out of the 33 criteria meet the acceptable standards. Processing challenges are eradicated from the model as a result of eliminating these criteria during the evaluation process. The valid supply chain disruption and resilience strategies hierarchical model consists of the following six aspects: (A1) supply risk, (A2) human issues, (A3) transportation failure, (A4) collaborative strategies, (A5) preventive resilience strategies and (A6) flexible business strategies (Table 4).

Table 3. FDM criteria evaluation results.

Initial criteria	D_b	Decision
Shortage in supply	0.650	Accepted
Supply cost risk	0.676	Accepted
Unreliable suppliers	0.536	Unaccepted
Financially distressed suppliers	0.667	Accepted
Technology breakdown	0.555	Unaccepted
Machine failures	0.577	Unaccepted
Structural risk	0.556	Unaccepted
Fire risk	0.570	Unaccepted
Electrical risk	0.553	Unaccepted
Shortage of skilled manpower	0.579	Unaccepted
Workers suspended production	0.651	Accepted
Discriminated against female workers	0.568	Unaccepted
Inadequately skilled operator	0.659	Accepted
Lack of transport productive crews	0.558	Unaccepted
Poor transportation system	0.692	Accepted
Shortage of containers	0.526	Unaccepted
Wide transportation costs	0.644	Accepted
Partnership management	0.683	Accepted
Risk and revenue sharing	0.681	Accepted
Cooperation with stakeholders	0.685	Accepted
Market collaborative innovation	0.676	Accepted
Business-government collaboration	0.688	Accepted
Supply diversification strategies	0.678	Accepted
Quality assurance	0.574	Unaccepted
AI technologies	0.553	Unaccepted
Risk management culture	0.641	Accepted
Logistics and inventory management	0.583	Unaccepted
Computerized planning systems tools	0.662	Accepted
Innovating production processes	0.566	Unaccepted
Supplier development	0.578	Unaccepted
Digital transformation	0.680	Accepted
Just-in-time delivery	0.657	Accepted
Backup suppliers	0.675	Accepted
Threshold	0.621	

Table 4. Valid supply chain disruption and resilience strategies hierarchical model.

Aspect		Criteria	
A1	Supply risk	C1	Shortage in supply
		C2	Supply cost risk
		C3	Financially distressed suppliers
A2	Human Issues	C4	Workers suspended production
		C5	Inadequately skilled operators
A3	Transportation failure	C6	Poor transportation system
		C7	Wide transportation costs
A4	Collaborative strategies	C8	Partnership management
		C9	Risk and revenue sharing
		C10	Cooperation with stakeholders
		C11	Market collaborative innovation
		C12	Business-government collaboration
A5	Preventive resilience strategies	C13	Supply diversification strategies
		C14	Risk management culture
		C15	Computerized planning systems tools
A6	Flexible business strategies	C16	Digital transformation
		C17	Just-in-time delivery
		C18	Backup suppliers

4.2. Fuzzy decision-making trial and evaluation laboratory results

To address the uncertainty denotations and transform those linguistic preferences into synthetic crisp value notations (shown in Table 5), the TFNs in the FDEMATEL analysis are normalized via Equations (3) through (6).

Equations (7) and (8) are used to obtain the synthetic crisp values and then enter them into a matrix of interrelationships. The cause–and–effect diagram is generated by analyzing the causal and dependent forces via Equations (9) and (10) to examine the interrelationships. The six components of the interrelationship matrix are transformed into causal interrelationships, as shown in Table 6. The total values of the rows and columns are determined by A and B. Aspects are categorized in the cause group if A − B is positive; otherwise, they are assigned to the effect category. The dataset is then mapped on [(A + B), (A − B)] to produce a causal connection for the aspects.

Figure 1 illustrates the causal interrelationship among the various aspects. The cause group consists of flexible business strategies (A6), supply risk strategies (A1), and collaborative strategies (A4), whereas the effect group consists of preventive resilience strategies (A5), human issues (A2) and transportation failure strategies (A3). The most significant indicator that affects the effectiveness of resilience strategies is flexible business strategies (A6) since these indicators nearly always have strong or moderate interrelationships with other indicators. The causal group has a significant effect on the effect group, making recognizing disruptions crucial for strengthening supply chain resilience. Flexible business strategies (A6) strongly influence collaborative strategies (A4) and moderate the effects on supply risk (A1), preventive resilience strategies (A5) and transportation failure (A3).

Furthermore, Table 7 demonstrates the causal correlation that can be seen between the criteria. The interdependence of the criteria is shown in Figure 2, whereby the criteria that are located above the horizontal axis are included in the group that is responsible for the cause. The group that is considered the effect includes the remaining criteria that are positioned beneath the horizontal axis. In terms of causes, the criteria that are considered the most essential are as follows: backup suppliers (C18), risk and revenue sharing (C9), risk management culture (C14), partnership management (C8), and cooperation with stakeholders (C10).

Table 5. Synthetic crisp values notation for aspects.

	A1	A2	A3	A4	A5	A6
A1	0.706	0.430	0.541	0.571	0.545	0.541
A2	0.428	0.733	0.441	0.518	0.480	0.498
A3	0.517	0.455	0.686	0.569	0.543	0.483
A4	0.560	0.539	0.580	0.717	0.534	0.574
A5	0.550	0.468	0.555	0.523	0.697	0.538
A6	0.557	0.593	0.545	0.642	0.594	0.644

Table 6. Interrelationship matrix and causal interrelationships among aspects.

	A1	A2	A3	A4	A5	A6	A	B	(A + B)	(A – B)
A1	3.670	3.467	3.655	3.865	3.699	3.575	18.356	17.918	36.274	0.438
A2	3.314	3.301	3.350	3.560	3.402	3.295	16.926	17.292	34.218	(0.365)
A3	3.519	3.383	3.602	3.763	3.601	3.464	17.868	18.099	35.968	(0.231)
A4	3.801	3.671	3.843	4.096	3.874	3.758	19.286	19.123	38.409	0.162
A5	3.614	3.470	3.649	3.840	3.734	3.565	18.307	18.310	36.617	(0.004)
A6	3.871	3.756	3.904	4.150	3.965	3.849	19.647	17.658	37.305	1.989

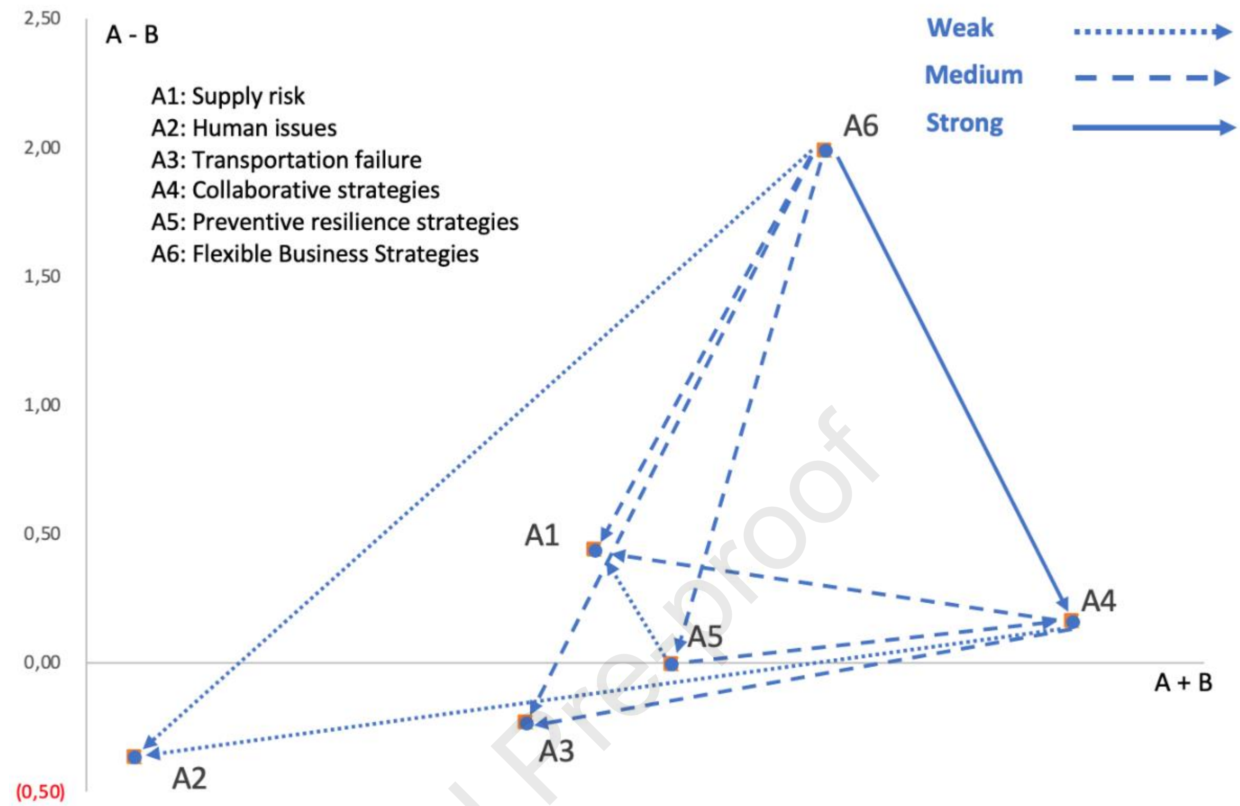


Figure 1. Causal interrelationship diagram for aspects.

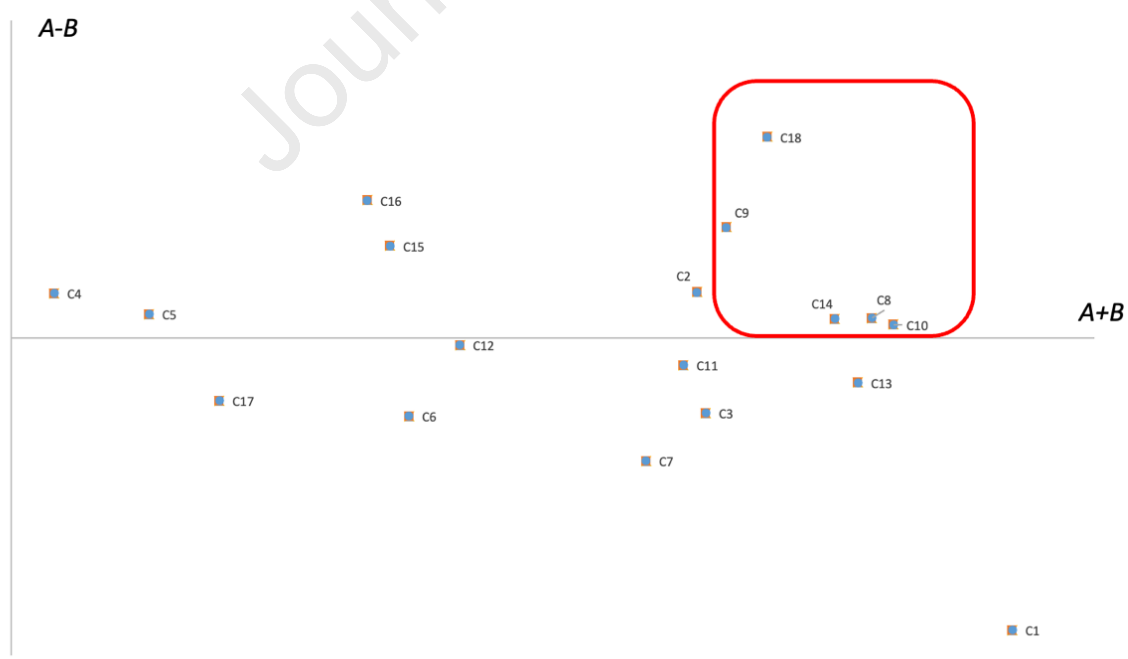
Table 7. Inter-relationship matrix among criteria.

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15
C1	1.051	0.928	0.945	0.791	0.797	0.879	0.935	0.960	0.901	0.960	0.924	0.877	0.968	0.948	0.839
C2	1.019	0.926	0.932	0.772	0.785	0.851	0.909	0.942	0.900	0.937	0.903	0.862	0.951	0.937	0.830
C3	1.004	0.902	0.928	0.766	0.779	0.835	0.902	0.928	0.882	0.929	0.888	0.849	0.915	0.922	0.817
C4	0.869	0.774	0.788	0.705	0.700	0.736	0.780	0.798	0.766	0.811	0.771	0.735	0.808	0.808	0.724
C5	0.879	0.786	0.804	0.698	0.737	0.760	0.790	0.823	0.784	0.827	0.791	0.751	0.819	0.825	0.735
C6	0.924	0.823	0.837	0.711	0.732	0.823	0.851	0.868	0.817	0.865	0.835	0.791	0.858	0.849	0.765
C7	0.970	0.859	0.880	0.735	0.755	0.843	0.907	0.916	0.874	0.915	0.874	0.830	0.906	0.897	0.801
C8	1.049	0.929	0.952	0.787	0.819	0.894	0.955	0.991	0.934	0.979	0.944	0.897	0.972	0.959	0.855
C9	1.023	0.914	0.939	0.783	0.805	0.866	0.934	0.961	0.936	0.956	0.918	0.883	0.960	0.944	0.843
C10	1.046	0.935	0.954	0.799	0.826	0.898	0.950	0.974	0.936	1.000	0.946	0.898	0.985	0.967	0.855
C11	0.984	0.883	0.903	0.755	0.778	0.851	0.899	0.929	0.890	0.939	0.921	0.860	0.939	0.914	0.815
C12	0.948	0.850	0.869	0.715	0.742	0.809	0.857	0.888	0.856	0.898	0.871	0.843	0.883	0.867	0.777
C13	1.033	0.923	0.932	0.775	0.807	0.865	0.929	0.951	0.921	0.970	0.937	0.875	1.017	0.947	0.844
C14	1.034	0.926	0.945	0.794	0.827	0.870	0.933	0.954	0.921	0.968	0.930	0.878	0.968	0.976	0.867
C15	0.942	0.847	0.863	0.737	0.756	0.804	0.852	0.878	0.835	0.878	0.851	0.800	0.883	0.880	0.816
C16	0.941	0.837	0.856	0.737	0.757	0.816	0.857	0.881	0.847	0.882	0.852	0.808	0.883	0.882	0.805
C17	0.883	0.784	0.803	0.680	0.699	0.767	0.805	0.820	0.792	0.826	0.795	0.740	0.834	0.820	0.741
C18	1.055	0.939	0.951	0.802	0.818	0.895	0.944	0.968	0.922	0.982	0.938	0.893	0.987	0.966	0.864

Table 8. Causal interrelationships among criteria.

	A	B	A+B	A-B
C1	16.276	17.656	33.931	(1.380)
C2	15.981	15.765	31.747	0.216
C3	15.727	16.081	31.808	(0.354)
C4	13.754	13.543	27.297	0.211
C5	14.034	13.921	27.956	0.113
C6	14.693	15.062	29.755	(0.370)
C7	15.406	15.988	31.394	(0.581)
C8	16.526	16.431	32.958	0.095
C9	16.238	15.714	31.951	0.524
C10	16.586	16.523	33.109	0.063
C11	15.764	15.891	31.655	(0.128)
C12	15.037	15.070	30.107	(0.033)
C13	16.325	16.535	32.861	(0.210)
C14	16.397	16.306	32.703	0.091
C15	15.029	14.593	29.623	0.436
C16	15.057	14.407	29.464	0.650
C17	14.073	14.369	28.442	(0.296)
C18	16.592	15.642	32.234	0.950

Figure 2. Causal diagram of the criteria.



5. Implications

In this section, this study addresses both the theoretical and practical implications.

5.1. Theoretical implications

Supply risk is a crucial factor in supply chain disruption that significantly influences the resilience and vulnerability of supply networks. Supply risk pertains to the possibility of disruptions in the supply of necessary commodities and resources for manufacturing, which may occur due to causes such as supplier bankruptcy, geopolitical events, natural catastrophes, and market instability. The aforementioned risks have the potential to cause substantial disruptions, resulting in delays, escalated expenses, and diminished product availability. These factors ultimately have a direct influence on a company's overall performance and competitiveness (Shekarian & Mellat, 2021; Song et al., 2024). In addition, including supply risk in the study of supply chain disruptions enhances the creation of complete risk management frameworks. This integration enables researchers to construct more advanced models that accurately represent the intricate and interdependent structure of global supply networks. Furthermore, comprehending these dynamics aids in pinpointing crucial nodes and weaknesses within the supply chain, thereby enabling the development of more efficient solutions to mitigate risks (Piprani et al., 2022). In the linked and globalized context of contemporary supply chains, a disruption at one supplier may have a cascade effect, impacting numerous layers and leading to significant operational issues. Through the timely evaluation of these risks, firms may formulate measures such as expanding their supply network and establishing comprehensive contingency plans. Therefore, it is crucial to recognize and address supply risk to ensure the efficient operation of supply chains and reduce the negative impact of interruptions on company activities.

Collaborative strategies are essential for strengthening supply chain resilience during disruptions, providing substantial practical benefits and contributing to theoretical progress. Collaborative strategies may be implemented by engaging in shared risk assessments, conducting collaborative contingency planning, and facilitating real-time information sharing. These practices allow all involved parties to better predict, react to, and recover from disruptions in a more efficient and effective manner (Duong & Chong, 2020). Through the use of their respective strengths and skills, supply chain partners may collaboratively improve their ability to withstand and recover from interruptions, thereby minimizing the negative effects and ensuring a consistent and uninterrupted flow of products and services. Moreover, a crucial element of collaborative solutions is the formation of cross-functional teams that combine knowledge from different areas of the supply chain to address particular issues, such as unexpected increases in demand or shortages in supply. Through the examination of these techniques, scholars may discern optimal methods and formulate recommendations that companies can adhere to in order to construct more robust and adaptable supply chains (Shekarian & Mellat, 2021; Yan et al., 2023). By using the combined capabilities and resources of all stakeholders, collaborative strategies are crucial for developing supply chain resilience. These tactics improve the efficiency of practical operations by integrating networks, exchanging technology, and establishing risk-sharing agreements. Additionally, they strengthen theoretical models by offering valuable insights into efficient cooperation and risk management. The result is a more robust, adaptive, and resilient supply chain that is capable of maintaining stability and performance in the face of various disruptions.

Flexible business strategies enable companies to customize their reactions according to unique disruption circumstances. The capacity to adapt allows organizations to avoid being limited by inflexible procedures and instead create solutions that are tailored to individual circumstances, thus improving overall disruption management. When supply chains are seen as complex adaptive systems, flexible strategies encourage characteristics such as self-organization, learning, and adaptability. These solutions allow supply chain entities to adapt and reorganize in response to shocks, hence improving the resilience and strength of the system (Canwat, 2024). Adopting flexible business strategies may minimize the expenses incurred due to disruptions in the supply chain. This is achieved by enhancing communication, decreasing ambiguity, and enhancing collaboration among partners. The decrease in transaction costs results in improved efficiency and effectiveness in managing disruptions. In addition, adaptable business strategies may optimize the use of existing buffers by increasing resource availability and utilization across various phases of supply, process, and demand in supply chains (Rajesh, 2021). By incorporating and expanding upon several strategies, these approaches provide a strong basis for building resilient, adaptable, and efficient supply chains. This study highlights the importance of adaptability in effectively navigating the intricacies of contemporary supply chain settings and provides significant insights for both academic and practical purposes.

5.2. Managerial implications

Partnership management (C8) plays a pivotal role in enhancing supply chain resilience within the garment industry through fostering robust, collaborative relationships with suppliers, logistics providers, and other key stakeholders. Beyond mere transactional exchanges, effective partnership management entails strategic alignment of goals, values, and operational strategies, ensuring that all parties work toward shared objectives. Partnership management strategies also facilitate continuous improvement initiatives and innovation efforts across the supply chain. Through the combination of resources and specialized knowledge, stakeholders can collaborate to invest in the research and development of novel materials, technologies, and sustainable methods. This not only improves the quality of products and operational efficiency but also meets the growing demands of stricter regulations and consumer expectations for ethical sourcing and environmental responsibility. Managers should promote a culture of innovation and sustainability within partnerships, encouraging the adoption of new technologies and practices that enhance product quality, operational efficiency, and environmental stewardship. In addition, efficient partnership management promotes a culture of resilience and adaptation in the garment industry, where stakeholders work together to overcome obstacles and exploit chances for expansion. Companies may enhance the success of their joint efforts by including feedback systems and performance measures in their partnership agreements, allowing for ongoing monitoring and improvement. In the end, by fostering robust collaborations founded on mutual respect, openness, and common objectives, participants in the garment industry can establish a durable and adaptable supply chain that not only endures disruptions but also stimulates sustainable expansion and a competitive edge in the global market.

Risk and revenue sharing (C9) has a crucial effect on improving supply chain resilience in the garment industry by establishing a fair and cooperative method of handling risks and dispersing rewards. Through the implementation of risk- and income-sharing agreements, firms and their suppliers may establish a stronger alignment of interests, guaranteeing that both parties have an equal stake in the prosperity and reliability of the supply chain. This collaborative framework promotes open and clear communication and cooperative problem solving, facilitating faster and more efficient reactions to disturbances such as shortages of materials, delays in production, or changes in the market. By engaging in risk sharing, such as distributing the expenses associated with raw material price hikes or logistical interruptions, the financial strain on individual entities is lessened. This facilitates the implementation of contingency plans and the ability to sustain operations during times of crisis. This collective obligation promotes a feeling of collaboration and reciprocal confidence, as suppliers and manufacturers collaborate to address disruptions or overcome problems. Moreover, this financial alignment serves as an incentive for suppliers to invest in advanced technology, embrace superior methods, and consistently enhance their operations, hence resulting in advantages for the whole supply chain. Managers should consistently participate in planning sessions and collaborative decision-making procedures that are established to collaboratively identify possible risks, create strategies to minimize them, and exploit chances for improvement. In summary, the implementation of risk and income sharing mechanisms in the garment industry leads to a supply chain that is more robust, flexible, and able to compete effectively. It empowers all stakeholders to better endure obstacles, leverage favorable circumstances, and guarantee a consistent, high-quality provision of products to the market.

Cooperation with stakeholders (C10) is essential for improving the resilience of the garment supply chain by promoting a coordinated approach to managing risks and addressing problems together. Garment manufacturers can establish a network by actively collaborating with suppliers, customers, logistics providers, and regulatory bodies. This network facilitates the exchange of information and resources, allowing for the quick detection and resolution of potential disruptions, particularly in the case of raw material shortages in Vietnam's garment industry. This cooperative framework fosters openness and confidence, guaranteeing that all parties are in agreement with their goals and tactics, which is essential for smooth operations. Moreover, when stakeholders engage in cooperative scheduling and share resources, improved inventory management, decreased lead times, and streamlined logistics procedures result, ultimately increasing the overall efficiency of the supply chain. Therefore, by enhancing enduring alliances with suppliers, making substantial investments in their growth, and pioneering sustainable practices and manufacturing techniques together, trust and dependability are promoted across the supply chain. In addition, organizations should improve the efficiency of their logistics, expand their distribution channels, and establish joint programs for compliance and risk management to collectively reduce risks. Garment firms may establish a robust supply chain that effectively responds to problems and maintains long-term success in a competitive market by promoting a culture of cooperation, constant development, and shared accountability.

The establishment of a risk management culture (C14) inside firms is essential for maintaining operational stability and promoting a proactive approach to recognizing and reducing possible dangers. By instilling risk awareness across all levels of the organization, ranging from top-level management to workers on the manufacturing floor, firms may effectively predict and promptly address potential disruptions, such as supply chain outages, regulatory modifications, natural catastrophes, or market instability. This comprehensive risk management strategy involves conducting frequent risk assessments to identify vulnerabilities and possible repercussions. It also entails creating contingency plans that explain specific measures to be performed in response to different situations. These strategies improve the capacity to sustain production without disruption and protect against financial setbacks by ensuring the availability of alternative suppliers, manufacturing techniques, and logistical solutions in the supply chain. Moreover, a risk management culture fosters the ongoing surveillance and enhancement of procedures, resulting in elevated quality benchmarks and enhanced adherence to global rules. By adhering to labor regulations and environmental norms, the firm not only maintains product quality and meets consumer expectations but also safeguards its brand and avoids legal fines. Adopting a risk management culture encourages innovation by motivating organizations to pursue more robust and sustainable practices. These strategies include diversifying supplier bases, investing in new technology, and adopting eco-friendly materials and processes. Regularly assessing the efficacy of risk strategies, integrating risk management into everyday operations, and forming a dedicated crisis management team will foster a robust and adaptable corporate culture that can effectively navigate risks and support long-term development.

Back-up suppliers (C18) in the garment industry play a vital role in maintaining operational continuity and promoting industry advancement via many important contributions. Having a backup supplier is a strategy that helps reduce risks by providing flexibility in the case of disruptions such as natural disasters, supplier failures, or transportation issues and ensures that production and delivery schedules can be maintained without disruption. In the context of Vietnam, this strategy offers flexibility in managing capacity and allows garment makers to quickly react to increases in demand during peak seasons and thus attempt not to cause shortages in material supplies. It also provides extra production capacity when the main suppliers are limited. By providing a wide range of choices, manufacturers are allowed to explore new opportunities for creating products, quickly adapt to changing customer preferences, and distinguish themselves in competitive marketplaces. The backup supplier has the advantage of being able to easily adjust to market fluctuations or interruptions in the supply chain while also promoting sustainability and adherence to ethical standards. Practitioners should establish effective lines of communication with alternative suppliers to enable proactive planning and quick responses to market fluctuations or unexpected circumstances. Garment manufacturers may increase their bargaining power, prevent excessive pricing, and guarantee a consistent supply of superior materials by establishing connections with several suppliers. As a result, backup suppliers play a multifaceted role that extends beyond mere contingency planning, shaping a robust and adaptable supply chain capable of meeting diverse challenges in the dynamic garment market.

6. Conclusion

Investigating supply chain disruptions and implementing resilience strategies is crucial for sustaining company operations and gaining a competitive edge in an ever-changing global market. Disruptions may arise from several causes, including supplier risks, human-related concerns, and transportation failures, resulting in substantial delays, heightened expenses, and degraded product quality. Through the identification of vulnerabilities and the implementation of resilience measures, firms may effectively reduce risks, guarantee smoother operations, and promptly adjust to unexpected obstacles. The use of preventive, concurrent, and reactive measures not only ensures the protection of financial performance but also improves the general sustainability and dependability of the supply chain. Hence, practitioners must recognize the signs of supply chain disruption and provide measures that strengthen the resilience of the supply chain under unpredictable conditions. This study presents a comprehensive framework consisting of six aspects and eighteen criteria that can be used to assess supply chain disruptions and strategies and enhance resilience. The FDM is used to determine accurate indicators by converting linguistic preferences into precise numerical values. The FDEMATEL method is used to identify the interrelationships between cause-and-effect attributes and enhance the supply chain performance of garment manufacturers.

In the initial hierarchical model, an attribute set that has 33 criteria based on eight different aspects is suggested. There are 18 criteria, and six aspects are retained as valid components of the hierarchical model for supply chain disruption and resilience strategies. The established causal interrelationships show that supply risk, collaborative strategies, and flexible business strategies are recognized as the causative factors of supply chain disruption and resilience strategies. In particular, flexible business strategies have a significant influence on collaborative strategies, as do interactions with other network elements, whereas collaborative strategies have a moderate effect on supply risk, transportation failure and preventive resilience strategies. For practices, backup suppliers, risk and revenue sharing, risk management culture, partnership management, and cooperation with stakeholders were the criteria groups that significantly contributed to enhancing the success of supply chain disruption.

This study makes significant theoretical and practical contributions to the garment industry's efforts to improve supply chain resilience and effectively manage disruptions. The theory of supply chain disruption and resilience strategy indicators provides a solid foundation for the advancement of the academic literature, as well as the identification and implementation of effective strategies to improve operational performance. The theoretical framework of the hierarchical model of supply chain disruption and resilience strategies can identify indicators of disruptions and contribute to the resilience of supply, thus identifying prompt strategies to help enhance supply chain disruption. (1) Supply risk is recognized to assist organizations in swiftly evaluating these risks and developing solutions, such as diversifying their supplier base and implementing comprehensive contingency plans; (2) collaborative strategies may improve practical operations by integrating networks, exchanging technology, making risk-sharing agreements and strengthening theoretical models by offering valuable insights into successful cooperation and risk management; (3) flexible business strategies help reduce transaction costs associated with supply chain disruptions by streamlining communication, thereby reducing uncertainty and improving coordination among partners. Moreover, this study offers practical applications for the implementation of garment industry practices in Vietnam. Companies may use several resilience tactics, such as collaboration and flexibility, to improve performance during disruptive events.

Nevertheless, despite significant progress, this research still has several limitations. Although this research successfully identifies and confirms supply chain disruption and resilience strategies from the literature, there is currently an insufficient level of detection of these indicators, which hinders the thorough addressing of the issue. Subsequent research might build upon these discoveries and include more characteristics within a hierarchical framework for comprehensive assessment. Furthermore, this specific research examines only the garment industry in Vietnam. For future research, identifying supply chain disruption indicators specific to different industries and comparing them across geographical regions are recommended approaches. Additionally, applying a hierarchical model of resilience strategies can enhance the supply chain in those specific industries, thus assuring the model's generalizability. Ultimately, the committee used herein consists of a mere 15 specialists who have expertise in this subject matter and are actively engaged in the decision-making process, potentially influencing the final results. Subsequent research aimed at addressing this problem should include a greater number of experts in this particular domain.

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Appendix A. Initial aspects and criteria.

Aspect		Criteria		Description	References
A1	Supply risk	C1	Shortage in supply	Refers to a shortfall in supply and an inadequate quantity of a certain product, material, or resource available to match the demand.	Panwar et al., 2022; Rajesh, 2021; Islam et al., 2022; Wagner et al., 2022
		C2	Supply cost risk	Pertains to the manufacturer relinquishing control over material prices, specifically as a result of relying on a single source, which may lead to disruptions.	
		C3	Unreliable supplier	Reflects that the supplied amount of materials is consistently lower than the predicted quantity.	
		C4	Financially distressed suppliers	Substantial financial challenges or instability; may lead to supply shortages or disruptions in the delivery of raw materials, ultimately causing delays, shortages, or a decline in income for downstream firms.	
A2	Processing Challenges	C5	Technology breakdown	Refers to software flaws, hardware problems, and network outages, which are the primary causes of technology failures in the industrial sector.	Shekarian & Mellat, 2021; Praharsi et al., 2021; Maalouf & Hoque 2022
		C6	Machine failure	Refers to instances when machines do not operate smoothly or are not well configured for the specific fabric used in the manufacturing process, which may lead to disruptions.	
		C7	Structural risk	Concerned with the structural integrity of buildings and protection from building collapse.	
		C8	Fire risk	Concerned with the compliance of a garment building to fire safety requirements and protection from the effects of fire and the associated smoke, heat, and toxic gasses.	
		C9	Electrical risk	Refers to the compliance of a building to electrical safety requirements and protection from electrical hazards.	
A3	Human Issues	C10	Shortage of skilled manpower	Industry owners may lay off skilled manpower to cut costs.	Paul et al., 2021;

		C11	Workers suspended production	Manufacturing or production activities are either stopped or greatly reduced due to the suspension of workers. This suspension is typically caused by poor working conditions, unsafe factories, low worker salaries, unpaid wages or delayed payment, worker abuse, social welfare issues, and other related problems.	Handfield et al., 2020; Maalouf & Hoque, 2022; Fartaj et al., 2020
		C12	Discriminated against female workers	This includes instances of verbal abuse, sexual harassment, public humiliation due to failure to fulfill objectives, excessive workload, inadequate remuneration, and compulsory overtime.	
		C13	Inadequately skilled operator	Refers to the lack of knowledge of the operators, including newly appointed unskilled machine operators and operators who either do not understand or understand with variation in regard to the garment line.	
A4	Transportation failure	C14	Lack of transport productive crews	Refers to a scenario when there is an insufficient number of staff available to operate transportation vehicles, such as trucks, ships, trains, or aircraft.	Praharsi et al., 2021; Fartaj et al., 2020; Liu et al., 2023
		C15	Poor transportation system	Refers to inefficiencies in the supply chain that cause delays in the procurement and delivery processes.	
		C16	Shortage of containers	Hampers industrial operations and disrupts supply chains, resulting in unanticipated financial losses for enterprises and the prolonged storage of available-to-promise items in warehouses.	
		C17	Wide transportation costs	Escalation of transportation expenses, such as railway haulage charges, hinterland transportation prices, port tariffs, fuel costs, and other related factors, resulting in elevated industry-wide transportation costs.	
A5	Collaborative Strategies	C18	Partnership management	Involves effectively managing partnerships, establishing and maintaining long-term, strategic relationships with suppliers, manufacturers, and other service providers.	Liu et al., 2023; Al Naimi et al., 2022; Habib et al., 2022; Yan et al., 2023

		C19	Risk and revenue sharing	Refers to partners working together to identify and address potential hazards in the supply chain, thereby enhancing the competitive advantage of all the partners involved.	
		C20	Cooperation with stakeholders	Involves suppliers, manufacturers, and buyers exchanging expertise, information, risks, and rewards; represents a crucial strategic activity.	
		C21	Market collaborative innovation	The practice of supply chain focal enterprises working with stakeholders to consistently extend the market area, increase marketing channels, and explore prospective needs.	
		C22	Business-government collaboration	The implementation of supporting policies and regulations by governments on trade and finance, as well as the collaborative development of trade facilitation procedures and the establishment of a joint committee, all of which could effectively enhance trade facilitation.	
A6	Preventive Resilience Strategies	C23	Supply diversification strategies	Refers to a manufacturer's approach of mitigating the risk of supply interruptions by enhancing supplier redundancy.	Lou et al., 2024; Mirtsch et al., 2023; Song et al., 2024; Al Naimi et al., 2022; Islam et al., 2023; Katsaliaki et al., 2022
		C24	Quality assurance	The systematic process of creating, manufacturing, evaluating, and analyzing goods to ensure that they satisfy the intended level of quality for the company's target market.	
		C25	AI technologies	The potential to efficiently plan, control, and schedule the production of clothing; optimize production processes; improve the quality of the product; develop the right products by quickly extracting customer expectations; sense the market; optimize internal and external supply chains; and stimulate creativity in the workforce by automating business processes.	
		C26	Risk management culture	Refers to developing supply chain resilience within the organization, which helps the organization to identify the possibility of risks and increases the capability of the	

				supply chain to alleviate risks and reduce its vulnerability.	
		C27	Logistics and inventory management	Includes the efficient transportation, storage, and delivery of materials and completed goods, while also ensuring that the appropriate inventory levels are maintained to fulfill consumer demand without excess or shortages.	
		C28	Computerized planning systems tools	Software that assists with the scheduling of operations, timely rescheduling in the event of disruptions, and the retrieval of enterprise data from a single access point.	
A7	Flexible Business Strategies	C29	Innovating production processes	Refers to improvements in efficiency, quality, sustainability, and flexibility, all of which mitigate the negative effects of garment manufacturing processes.	Islam et al., 2021; Maalouf & Hoque 2022; Song et al., 2024; Sarker, 2020; Al Naimi et al., 2022
		C30	Supplier development	The strategic initiatives undertaken by a purchasing organization to improve the skills of its suppliers and optimize the procedures within the supply chain.	
		C31	Digital transformation	Refers to transforming the garment company activity into a sustainable business by closely monitoring and ensuring that suppliers adhere to the brand's principles and policies, as well as by minimizing polluting gas emissions and environmental damage along every step of the supply chain.	
		C32	Just-in-time delivery	Minimizes the inventory level, reduces waste, improves quality, and avoids long-term inventory holding.	
		C33	Backup suppliers	Refers to acquiring supplies from other sources in case of any interruption to production time or yield, thereby ensuring the continuity of production operations.	

Appendix B. Respondents' demographic profile

Respondent	Position	Year of experience	Education
1	Researcher	7	Doctoral
2	Lecturer	12	Masters
3	Researcher	4	Bachelors
4	Officer	2	Bachelors

5	Officer	2	Bachelors
6	Lecturer	9	Masters
7	Researcher	8	Masters
8	Government officer	4	Bachelors
9	Researcher	10	Doctoral
10	Researcher	5	Masters
11	Government officer	7	Masters
12	Researcher	2	Bachelors
13	Lecturer	5	Masters
14	Researcher	4	Bachelors
15	Researcher	2	Bachelors

Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐ The author is an Editorial Board Member/Editor-in-Chief/Associate Editor/Guest Editor for *[Journal name]* and was not involved in the editorial review or the decision to publish this article.

☐ The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: