An Analysis of Fuzzy Group Decision Making to Adopt Emerging Technologies for Fashion Supply Chain Risk Management

Piyya Muhammad Rafi-Ul-Shan, Mahdi Bashiri, Muhammad Mustafa Kamal, Sachin Kumar Mangla, and Benny Tjahjono

***Abstract*—The dynamic and volatile nature of fashion supply chains (FSCs) has drawn increasing attention from academia and the corporate sector. Fashion products, characterized by short life-cycles, impulse buying, and an unpredictable demand, necessitate that FSC partners rapidly offer on-trend products to capture the real-time demand in the shortest time window. To achieve this, FSC partners must embrace technological innovations, collaborate, and establish partnering relations, and share real-time information. Failure to do so will result in obsolete inventory and financial markdowns. In this article, we focus on identifying risk categories in FSC, such as social, environmental, economic, operational, reputational, market, product, disruption, complexity, and workforce, along with relevant mitigation strategies. A survey questionnaire is distributed to six fashion companies in the U.K., employing the fuzzy group analytical hierarchy process for pairwise comparisons to assess the importance of each risk category. Fuzzy failure modes and effect analysis is used to analyze the impact of each risk mitigation strategy on the risk factors. This study supports the extant empirical research in which resource sharing is an effective risk mitigation strategy for fashion risk management. The study participants believe that designing resilient, flexible, agile, and responsive systems with increased levels of communication and information sharing with the help of emerging innovative technologies are the more robust mitigation strategies for fashion risk management. This study has evaluated the role of emerging technologies in risk management, confirming that information communication technology and artificial intelligence are the most effective technologies for managing potential risks in the fashion industry.**

***Index Terms*—Emerging technology, fashion supply chain (FSC), hybrid fuzzy analytical hierarchy process-failure mode and effect analysis (AHP-FMEA) method, mitigation strategy, risk analysis.**

I. Introduction

THE collapse of Rana Plaza, which housed the fashion manufacturers of leading international fashion brands, led to the death of 1129 workers, depicting the vulnerability of the fashion supply chain (FSC) due to the unknown risks in the geographically dispersed, complex, and invisible FSC operations [42]. Although the Rana Plaza disaster was the deadliest in FSC history, the risks and disruptions to FSC have a temporal record of events, such as the issues of child labor, poor working conditions, exploitation of the workforce, disruptions, and reputational risks [82]. Historically, FSC has been dealing with such events through diverse proactive and reactive approaches to identify and mitigate these risks by, for example, visits, audits, information sharing and communication, and building relationships [70]. Yet, the resilience of today's FSCs has proven to be ineffective, demonstrating a lack of preparedness for high-impact disruptions, such as COVID-19, the ongoing geopolitical tensions in Ukraine and Russia, inflation, and soaring sourcing costs due to the environmental impacts on raw material production [59]. McKinsey [63] reported that 85% of fashion businesses consider that factors, such as the Ukraine–Russia war, energy and climate crises, highest levels of inflation, and rises in price and the cost of living will negatively impact the growth of the fashion industry growth. Here, 84% of fashion executives perceive that 2023 could witness historic year-on-year volume declines. Thus, the fashion industry needs robust planning and decision making to be in place to navigate the uncertainties and risks in 2023 and beyond.

The fashion industry is highly global and fragmented into small and medium manufacturing plants concentrated in Asia and retail in Western economies [82]. FSCs have attracted the increased interest of academics and corporations alike due to their complex, volatile, and dynamic nature [59]. Furthermore, fashion products are characterized by a short life cycle, volatile and unpredictable demand, and impulse buying [77]. Fashion consumer decisions are based on *wants* instead of *needs*, necessitating the retail availability of on-trend products in the shortest time window possible to capture the real-time demand [9]. This requires FSC operational partners to be at the forefront of technological innovations to reduce the lead time and design flexibility duration, in addition to agile channels facilitating collaboration, real-time information sharing, and communication with their supply chain partners [18]. With significant and equally uncertain changes to consumer demands and geopolitical situations, the fashion industry must be proactive to determine the latest trends and be responsive to bringing those to the retail shelf along

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with reduced markdowns and financial losses due to product obsolescence [92].

Advanced manufacturing and communication technologies have facilitated information exchange and the ability to offer enhanced product variety and the outsourcing of even core competencies. However, this has also increased the consumer visibility of the business operations and, consequently, reduced the consumer tolerance of unethical and unsustainable business behaviors [100]. Thus, today's supply chains are highly exposed to scrutiny by multiple stakeholders, which implies that any exposure to unwanted events or disruptions at any supply chain tier can create vulnerabilities, including legal, financial, and reputational damage [82]. Scholarly research reports have reduced the effectiveness of organizational efforts to mitigate risks in their supply chain operations [22]. Makhashen et al. [59] argue that the existing risk mitigation strategies require robust analysis and evaluation by, for example, engaging and collaborating with multiple stakeholders in planning and decision making. For enhanced resilience and the increased effectiveness of risk mitigation strategies, scholarly research has also advocated the use of emerging technologies and interdisciplinary approaches with cooperative and partnering attitudes and behaviors [40], [100].

Supply chain digitalization (SCD) has emerged as a dynamic and effective process for managing the increased disruptions and risks in volatile and unpredictable business environments, such as fashion [45]. Digital innovative technologies have created enormous benefits for industries of all kinds [16] through, for example, increased transparency and well-informed decision making, as well as integrated and visible systems, a better understanding of customer requirements and service levels, and increased flexibility, adoptability, speed, risk management, and response time [29]. Nevertheless, SCD requires practitioners to make investments in innovative digital technologies and enabling structures and processes to make the global supply chain operations more connected, agile, and resilient to benefit from their superior value in the hands of the ultimate consumers [78], [79]. An investment in digital technologies needs a robust risk and disruptions analysis to be done as well as decision making to assess, evaluate, and design contingencies for potential risks and disruptions; otherwise, the intended objectives cannot always be achieved due to careless strategy formulation and implementation [24]. SCD is a disruptive and transformation process, which should be executed appropriately to avoid high risk and uncertainties during disruptive changes [102]. Technological, organizational, and environmental factors significantly impact the leveraging of innovative digital technologies; it is essential to understand SCDs purpose and strategy, as well as to analyze and evaluate what might happen during the process, and how the overall project might affect supply chain risk and disruptions management performance.

FSC scholars have highlighted numerous risks to FSC but the extant empirical research on fashion risk management is fragmented and disintegrated [59]. This impedes the efforts to understand the nature of risks and their relevant subfactors in FSC. Similarly, various researchers have reported diverse risk mitigation strategies in FSC, such as multiple sourcing to manage speed and supplier-related risks, planning and decision making, and workforce management [23], [41]. However, the existing accounts lack the provision of an integrated account of the risks, their subfactors, and relevant mitigation strategies. In addition, SCD is an emerging phenomenon that has revolutionized global supply chain operations through automation, real-time information sharing, and communication, increasing visibility and control and reducing lead times, as well as improving quality and customer service, to mention a few [14], [54], [78], [79], [100]. Despite the revolutionary and transformational impact of emerging innovative technologies on supply chain operational performance, their role in enhancing the effectiveness of FSC risk mitigation strategies has not yet been investigated. Thus, the purpose of this research is threefold:

1) to identify the main risks and their subfactors in FSC;
2) to identify the risk mitigation strategies in response to the identified risks;
2) to investigate the role of emerging innovative technologies to enhance the effectiveness of the identified risk mitigation strategies for FSCs.

In doing so, this research will help synthesize the fragmented research on FSC risk management. This will enable a better understanding of fashion risks, the evaluation of risk mitigation strategies, and highlight the most effective emerging technologies used in FSC risk mitigation strategies. The research questions of the current study are as follows.

1) *RQ1—What are the main risk factors for the FSC and what are their importance rates?*
2) *RQ2—What are the impactful risk mitigation strategies for the FSC?*
3) *RQ3—In terms of emerging technologies, which technology has more impact when adopting risk mitigation strategies?*

This study conducted a structured review of the extant empirical research to identify the main risks to FSCs, including their subfactors and relevant mitigation strategies. Similarly, the use of modern innovative technologies to mitigate FSC risks was also explored. This research applied a hybrid fuzzy decision-making method to deal with some of the linguistic variables. Because of making use of practitioners from the fashion industry, a group of fuzzy decision making was used in this research. The fuzzy analytical hierarchy process (AHP) helped us to identify the weights of the risk factors. On the other hand, the fuzzy failure modes and effects analysis (FMEA) provided a systematic method, which evaluates the risk mitigation strategies. This method helped to answer the research questions in a systematic manner.

The rest of this article is organized as follows. The literature review is presented in Section II. The research method is justified in Section III, followed by presenting the research findings and discussions and analysis in Sections IV and V. Finally, Section VI concludes this article.

II. Literature Review

A. FSC Risk Management

Fashion product characteristics and the fast-changing consumer tastes and preferences with great choice and availability create a greater likelihood of exposure to vulnerabilities and risks in FSCs [59], [77]. FSC management research has reported numerous risks, for example, financial risks arise from stock-outs, markdowns, and product obsolescence. Similarly, distorted information, mistrust, overreactions, second guessing, and unnecessary interventions cause chaos risks [23]. Failing to spot market trends or being slow to meet on-trend demand leads to market risks that demonstrate the critical importance of agility, the use of innovative technologies, reducing cycle times, increasing flexibility and market sensitivity to survive, and growing in a volatile and unpredictable fashion marketplace [31]. The global spread of the fashion manufacturing and retail industry also demonstrates its vulnerability to ethical and reputational perspectives, such as following the Rana Plaza incident and including the risks of transportation and distribution delays and disruptions, inaccurate inventory and material forecasting, product and trend obsolescence, a lack of capacity, quality issues among manufacturers and suppliers, and a lack of supply chain knowledge and resources for use in risk management [31], [42], [82].

The fashion industry is also vulnerable to sustainability risks because of the criticisms of its high environmental footprint in terms of water pollution due to the use of toxic chemicals, carbon footprint, as well as its energy use and rate of transportation, and the increasing levels of textile waste due to the growth of fast fashion [97]. The global shift of production to developing countries has been linked to workers and natural resource exploitation, of being complacent to workplace abuse, of failing to provide living wages, and of overlooking standards of work [17], [42]. Empirical research suggests that most of the sustainability risks predominantly occur in the upstream levels of the supply chain where production takes place, and in countries where the protection of workers' rights is often inadequate or even nonexistent [76]. There is an increased expectation that buyers should adopt appropriate sustainable sourcing practices and ensure that these are also followed by their supply chain partners [42]. However, the competitive environment of FSCs, such as downward price pressure, the requirement for a quick response, and the power imbalance between the retailers and suppliers limits the ability of garment manufacturers to negotiate better terms of business, presenting a major challenge when looking to manage the risks [81].

Similarly, fashion retailers with longer lead times and a slow reaction time will run the risk of extra inventory costs and unsold items having to be marked down, reducing the profit margin [31]. With consideration, fashion retailers need to make tradeoffs between cost and lead time in sourcing location decisions and their relationship, considering the impact on customer service and financial risks. This also requires process alignment, internal and external operational and structural integration, flexibility, adoptability, collaborations with network partners, and using responsive and innovative communications' channels [92]. The fashion requirements of agility and flexibility have led to the use of many suppliers in fashion sourcing. However, fashion companies are also working with key suppliers and are looking to build strategic relationships with their network partners as well as competitors to ensure on-trend product availability and to manage disruptions and the volatility of demand [81].

B. Emerging Technologies

1) Emerging Technologies in SC: Covid-19-related government restrictions, such as prolonged store closure and maintaining social distancing, including the boom in e-commerce, have instilled the critical importance of the digital transformation of business operations by leveraging innovative emerging technologies [24], [66], [77]. While the corporate and industrial world is gradually surpassing the learning curve for Industry 4.0 ideas, the world is already evolving into Industry 5.0 [79]. Innovative technologies, defined as "newly invented technologies that can be incremental, radical, or disruptive, or existing technologies used in new ways to improve value for businesses and enhance life for humans by making it more convenient" [66, pp. 2], such as blockchain, Internet-of-Things (IoTs), artificial intelligence (AI), and big data analytics and their application in the supply chain management discipline, have positively impacted operational performance by increasing customer experience, speed, and efficiencies [90]. Emerging and new forms of data and technologies enable organizations to collect, analyze, and store diverse and unlimited amounts of data on risk and disruptions. Consequently, this helps in making supply chain risk management (SCRM) related informed decisions, enabling early risk detection, and reducing risk occurrence and risk severity levels [40], [78]. Furthermore, the digitization of supply chain operations is done by leveraging new and emerging forms of data and technologies that present opportunities for value creation and providing new solutions for managing global pandemics [78].

Supply chain technologies are instrumental in the effective and efficient implementation of SCRM strategies by enabling real-time information sharing and communication, increased visibility and control, the enhanced safety and security of people and infrastructure, and the assessment of risks in supply chain networks [45]. Emerging innovative technologies also help in developing advanced early warning systems, helping in the prevention of fraud, and managing financial risk through the detection of credit risk, understanding weak links in the supply chain, and understanding complex customer behaviors [12]. The use of innovative emerging technologies also enhances the predictability of risk occurrence and minimizes the magnitude of adverse events in supplier management, customer retention, and forecasting probabilities for bankruptcy and insolvency [50]. Lezoche et al. [55] reported that SCD enables firms to develop and implement a robust inventory management system by monitoring real-time material flows and reducing the risk of stock possibilities, resulting in improved customer service levels. Innovative emerging technologies further enable organizations to reduce uncertainties through autonomous and intelligent decision-making capabilities, consequently, and increasing supply chain efficiency, sustainability, flexibility, agility, and resilience [29].

Emerging innovative technologies transform supply chains into being data driven by capturing real-time data and storing and transforming it, followed by performing analytics, and enabling fact-based decision making [102], thus transforming operations and enabling the organization to build their capabilities through sensing, monitoring, control, and analysis (descriptive capabilities), enhancing detection and prediction (predictive capabilities), decision making (prescriptive capabilities), and adaptive learning [79]. Being able to sense, monitor, control, and analyze the situation increases the possibility that, in the accurate and timely detection of potential risks, it is most likely before their occurrence, hence, improving decision making and building resilience [45], [55]. For example, blockchain technology builds supply chain resilience by enhancing detection levels and the reduction of disruptions, enabling the implementation of preventive and proactive measures for risk mitigation, as well as providing multitier protection for supply chain networks [29]. Similarly, AI with machine learning and deep learning algorithms enables the analysis of big data and broadens the understanding of real-time events or events that have occurred, forecasting future events to a point and, consequently, facilitating strategic decision making [78].

2) Emerging Technologies in Fashion Industry: The use of emerging innovative technologies is strategically vital to design integrated and responsive FSCs for identifying the latest fashion trends and ensuring on-shelf availability during the short selling window [92]. Leading fashion brands integrate emerging innovative technologies, such as wearables, virtual, robots, augmented, and mixed reality, for a more inclusive, convenient, and sustained in-store, and online customer experience [90]. These processes mirror the organizational efforts to operate digitally while maintaining a realistic and interactive environment for an inclusive customer experience and customized service provision. Emerging innovative technologies help purchase decision making based on customer tastes, preferences, measurements, ethics, and sustainability [13]. For example, intelligent digital humans exhibit real human features and expressions, consequently, providing an individualized customer experience by sensing and responding to body language for size and fitness, thus resulting in greater customer experience and reduced returns due to being an appropriate size and fit. This elevates the cost pressures on fashion retail operations through return management and the burden on the natural resources due to less waste from return garments [90]. In addition, emerging fashion technologies also enhance transparency and result in a better reaction time and faster product development, including market trend analytics in real time, improved the productivity and innovation capability, as well as cost reduction through the automation of tasks, and increased access to global markets [104].

The emerging innovative digital technologies play a vital role in fashion production planning, scheduling, and design development by sharing real-time data, performing trends, and design analytics. This helps in decision making on new trends and reduces production lead times by electronic transfer of samples [14]. The digitalization of fashion operations has transformed fashion production into a smart factory through the integration of innovative technologies, for example, the codevelopment of design and production through augmented and virtual reality technologies [25]. However, leveraging innovative technology for sustained competitive advantage in the fashion industry, such as other industries, is a daunting task due to the growing challenges of consumer privacy concerns, the availability of resources and capabilities, organizational culture, technology standards, legal and competitive pressures, and the involvement of multiple stakeholders with varied interests in the wider global FSC networks [14], [25], [90], [100]. Similarly, Radanliev et al. [78], [79] reported that digital technologies and new and emerging forms of data also present challenges, such as connectivity, power and rang issues, cost and economic feasibility, the optimization of execution time, and lowering energy consumption capabilities to handle the data. This brought in data protection, tamperproofing, and privacy and security. Contrary to these challenges, the empirical research holds the benefits accrued from emerging innovative technologies and new and emerging forms of data, such as understanding, predicting, and estimating individual and collective actions, events, changes in behavior, time, and responses, which outweigh the challenges and costs of such technologies [78]. Thus, this motivates this research to investigate the use of emerging innovative technologies to investigate the effectiveness of FSC risk mitigation strategies.

C. Decision-Making Methods for Risk Analysis

The extant empirical research reported numerous risk factors and applied risk management processes used to mitigate risks through the use of various analytical tools in varied industrial contexts (see for example, [61], [72], [73], [86], [93], and [94]). Similarly, Junaid et al. [49] applied a neutrosophic AHP and the technique of order performance similarity to the ideal solution (TOPSIS) in the automotive industry for risk investigation. Mokrini and Aouam [69] applied an integrated fuzzy-based multicriteria decision analysis (MCDA) method for risk quantification in the healthcare sector. Abdel-Basset and Mohamed [1] applied plithogenic-based TOPSIS and CRITIC tools to assess sustainable supply chain management risks in the telecommunications industry. Ramesh et al. [83] applied a hybrid Decision-Making Trial and Evaluation Laboratory (DEMATEL) and ANP-based MCDA to assess the inbound supply chain risks in electronic industry supply chains. Ozturkoglu et al. [74] assessed risks in the ship recycling industry using a fuzzy-based DEMATEL approach. An artificial neural network model was applied by Rezaei et al. [85] to analyze the risks in the automotive aftermarket industry. Wang et al. [98] applied a two-stage fuzzy-AHP model to assess the risks when implementing green initiatives in FSCs. Although these studies have made useful contributions to the knowledge domain, they have not investigated the key risks to fashion, its relevant subfactors, and any mitigation strategies. Similarly, there are studies that have not investigated the role of emerging innovative technologies to enhance the effectiveness of FSC risk mitigation strategies, which motivates this research.

According to a literature review on supply chain risk analysis methods by Azadnia et al. [5] and other newly published studies,

TABLE I
SUMMARIZED REVIEW OF DECISION-MAKING METHODS FOR RISK ANALYSIS (SOURCE: ADAPTED FROM AZADNIA ET AL. [5])

Reference	Decision Making (N/A)	Industry/Sector	Region
Abdel-Basset and Mohamed [1]	Plithogenic TOPSIS-CRITIC	Telecommunications Equipment	China
Azadnia et al. [5]	Delphi-BWM	Green hydrogen for hard-to-abate sectors	Europe
Azevedo et al. [7]	N/A	Renewable Energy (Specify)	–
Babu and Yadav [8]	Overall Risk Index Evaluation with Fuzzy Numbers	Manufacturing SME	India
Ciotola et al. [21]	Holistic Risk Analysis and Modeling (HoRAM)	Renewable Energy (Vanadium)	Germany
Etemadi et al. [30]	N/A	Blockchain Technology	–
Jelti et al. [46]	N/A	Renewable Energy	–
Jianying et al. [47]	Single BP and Optimized BP Neural Networks	Fresh grape	China
Kim [51]	N/A	Renewable Energy	Korea
Lahane and Kant [52]	Pythagorean Fuzzy AHP and Pythagorean Fuzzy VIKOR	Manufacturing	India
Moktadir et al. [67]	Pareto Analysis and BWM	Leather	Bangladesh
de Oliveira et al. [105]	AHP	Automotive	Brazil
Pathak et al. [75]	Modified Delphi and AHP	Renewable Energy	India
Rangel et al. [80]	N/A	–	–
Rostamzadeh et al. [87]	Fuzzy TOPSIS-CRITIC	Oil	Iran
Shahbaz et al. [89]	N/A	–	–
Song et al. [91]	Rough Weighted DEMATEL	Telecommunications Equipment	China
Wee et al. [99]	N/A	Renewable Energy	
Current Study	Fuzzy AHP–Fuzzy FMEA	FSC	UK

it can be concluded that not only is this study novel considering its region and sector but also there is a contribution in the applied methods used for the analysis. A systematic literature review conducted by Liu et al. [57] on using multiple criteria decision-making methods for the FMEA confirmed that no published study has used a hybrid method of fuzzy AHP and fuzzy FMEA. Moreover, the studies that have either used AHP or TOPSIS inside the FMEA method have not been done in the FSC. According to a literature review on supply chain risk analysis methods by Azadnia et al. [5] and other newly published studies, the applied decision-making methods for the purpose of risk analysis have been summarized in Table I.

Based on Table I, it can be concluded that not only is this study novel considering its regional and industrial context but also there is a contribution in the applied methods for the analysis presented. In this study, the fuzzy group AHP has been used to evaluate and prioritize the importance of FSC risk factors and then the fuzzy FMEA technique has been used to quantify the current risk status of the FSC as well as its expected value following the adopting of each mitigation strategy. The proposed hybrid method provides an opportunity to discover the impact of each mitigation strategy to improve the occurrence probability, severity, and detectability of each risk factor by considering selected FSC to meet the decision-makers' opinions.

This study conducted a structured review of the extant empirical research to identify, analyze, and extract the key risks and their relevant subfactors, including mitigation strategies and applied innovative technologies in the fashion industry [26]. Following the article of Denyer and Tranfield [27], the structured review of the extant empirical research was conducted in four phases. *Phase I* was related to setting the research objectives, and designing keywords and search strings. The main objectives of this structured review were as follows:

1) to identify the key risks and relevant subfactors in the fashion industry;
2) to identify risk mitigation strategies in the fashion industry;
3) to identify applied innovative digital technologies in the fashion industry to mitigate fashion risks.

The key search strings were designed following boolean logic (see Appendix A) and in collaboration with the research team and an industry expert for validity and triangulation in order to achieve enhanced research quality and transparency [66], [103].

Phase II was related to ensuring research quality and transparency in the data collection, as well as the finalization of the research papers, which was ensured by providing a thick description and detailed trackability of the review processes and steps taken in each [66]. For example, this study selected three academic databases (Emerald Insight, ScienceDirect, and Web of Science) to search for empirical papers. The selected academic databases collectively index good quality, peer-reviewed research papers, provide holistic bibliographic data, and examine detailed abstracts and references from the most influential research [82], thus ensuring comprehensiveness, easy organizational access, and the analysis of the research data and results [59]. *Phases III* and *IV* were related to searching and screening the empirical papers and analysis for their relevance to the research subject areas. Newbert's [71] inclusion and exclusion criteria were applied to further enhance the research quality by including empirical research papers written in English, published from 2000 onward, and containing the chosen keywords in the title, abstract, or introduction. The applied structured approach to review the extant empirical research in the subject research domain enabled the researchers to finalize 120 papers discussing either risk in the fashion industry or the application of emerging innovative digital technologies, satisfying our inclusion–exclusion criteria. Table II provides the key risks and relevant subfactors in FSC, Table III provides the risk mitigation strategies in FSC, and Table IV provides the application of modern innovative technologies in FSC.

III. RESEARCH METHODOLOGY

A. Data Collection and Analysis Method

To collect the data for this research, an initial list of fashion companies was prepared through the U.K. Fashion and Textile Association, including their personal and online information. The fashion companies were approached via emails, and this was followed up by phone calls. Six U.K.-based fashion companies

TABLE II
KEY RISKS IN FSCS AND THEIR SUBFACTORS

Risk Types	SubFactors	Selected Sources
Social	- Child labor - Worker exploitation - substandard working conditions - under wage payments - health and safety issues - workforce redundancy - Employment risks	[17], [20], [34], [35], [41], [42], [59], [60], [61], [64], [77].
Environmental	- Water pollution - Carbon emissions - Packaging - Water Waste - Textile waste and landfill - high use of chemicals	[17], [20], [34], [35], [41], [42], [59], [64], [77], [81], [82].
Economic	- lost sales (stock-outs) - Environmental penalties - Product obsolescence - High operating costs - Price competition - Sudden cancellation of orders - Retailer pressures	[17], [20], [34], [35], [41], [42], [59], [64], [77], [81], 82].
Operational	- lack of real-time information sharing and communication - lack of collaboration and coordination - lack of internal and external integration - lack of agility and responsiveness - structural rigidity - lack of adaptability and Flexibility - Infrastructure Issues - Capacity and technological risks - Outsourcing of production - Lack of fashion SCM knowledge - lack of visibility and control - Increasing returns	[28], [34], [41], [59], [62], [64], [65], [81], 82].
Reputational	- Negative publicity - Lack supply chain visibility and control - Multiple interests of multiple stakeholders - Late deliveries - Product damage - quality issues - Move to a mixed supplier/manufacturer - Environmental, social, and ethical issues	[15], [17], [34], [35], [64], [77], [81], [82].
Market	- Dynamic, complex, unpredictable, and volatile - low-tech and labor intensive - greater bargaining power of retailers - declining disposable income and recession	[23], [28], [34], [41], [62], [64], [65], [81]; [96].
Product	- Short life cycle, volatile, and unpredictable demand - On-trend product availability (Impulse buying) - Poor demand forecasting - Consumer differences in attitude and behavior	[22], [23], [28], [34], [62], [64], [65], [81].
Disruptions	- strikes and boycott - natural and manmade disasters - supplier rationalization, reducing buffers, and inventories - Increased frequency and longer recovery time - chaos risks - Dependency risks - Machinery breakdowns	[34], [41], [59], [62], [64], [65], [81], [82].
Complexity	- cultural issues - Import-export and customs issues - fragmented industry - Geographic complexity - Strategic decisions of SC partners - Financial structures - stakeholder interventions - design complexities	[28], [34], [41], [59], [62], [64], [65], [81], [82].
Workforce	- Lack of knowledge - Lack of skills and capabilities - aging workforce - Lack of the young generation's interest	[62], [95], [96], [48], [28], [41], [81].

TABLE III
RISK MITIGATION STRATEGIES IN THE FASHION INDUSTRY

Strategy	Sources
Risk Avoidance, Risk Transfer, and Risk Sharing	[34], [41], [64].
Sourcing Strategy	[23], [28], [64].
Buffers and Safety Stock	[23], [41], [64], [65].
Planning and Decision	[23], [41], [64], [65].
Workforce and Management	[23], [41], [64], [65], [96].
Communication and Information Sharing	[28], [34], [59], [64], [81], [82].
Building Relationships	[28], [59], [64], [81], [82].
Designing a Resilient System/SC	[23], [59], [64].
Supply Chain Redesign	[22], [41], [64], [81], [82].
Using Technology	[28], [41] , [64], [81], [82], [92].
Audits, Inspection, and Monitoring	[34], [41], [64], [65].
Creating a Risk Management Culture	[22], [23], [28], [34], [41], [81], [82].
Insurance and Hedging	[64].
Resource Sharing	[28], [41], [64], [65], [81].

TABLE IV
USE OF TECHNOLOGIES IN FSCS

Type of Technological Application	Selected Sources from the Finalized Papers
RFID	[3], [6], [10], [11], [14], [44], [58].
Blockchain	[44], [104].
IoTs	[4], [11], [14], [44].
Robotics	[14], [54].
AI	[4], [11], [29], [37], [44], [54], [56], [90], [101], [104].
Enterprise Resource Planning Systems	[19], [44], [58].
Geocoded Tracking Systems/GPS	[14], [53].
Bar Coding Technology	[53], [84].
ICT/EDI	[3], [14], [44], [58].

agreed to participate in the research. The participating fashion companies represent a good mix of medium and large companies with various ages operating at different tiers in their supply chains, such as retail, manufacturing, and wholesale, providing supply chain-wide perspectives [81]. Most of the selected companies are family-owned businesses operating in luxury, fast fashion, and basic fashion market levels. Thus, the participating fashion companies have well-established history and knowledge about fashion risks, subfactors, mitigation strategies, and the use of technologies, providing this research with an opportunity to gain valid and reliable data. Table V provides further details on the participant fashion companies and related information.

A comprehensive questionnaire was devised to gather the data from practitioners employed in six fashion companies. The questionnaire was comprised of three distinct sections. In the first part, the respondents performed pairwise comparisons between various FSC risk factors and their corresponding subfactors. The second part aimed to assess the severity, detection, and occurrence of each risk factor (subfactor) and to score the effectiveness of the risk mitigation strategies. The final section of the questionnaire focused on emerging technologies and their potential to aid in risk mitigation. The respondents were provided with linguistic values on a scale of ten levels, which were subsequently transformed into triangular fuzzy numbers (TFNs). This approach was chosen to accommodate uncertainties and

TABLE V
RESEARCH PARTICIPANTS' COMPANIES PROFILE

Description	Date Established	No. of Employees	Sourcing Countries/ Regions	No. of Respondents
FC1 Fast fashion garments and premium quality fashion footwear designer, manufacturer, wholesaler, and retailer.	1960s	~800	Asia Pacific, China, UK, Southeast Asia, North America, Europe, and U.K.	4
FC2 Designer, manufacturer, wholesaler, and retailer of luxury fashion garments.	1780s	~1,000	UK and EU, New Zealand, Turkey, China, South Asia, North America, and Northeast Africa.	6
FC3 Fast fashion garments and accessories manufacturer and wholesaler.	1790s	~750	China, Korea, South Asia, Asia Pacific, Turkey, UK, & EU.	4
FC4 Luxury garment and accessories designer, manufacturer, wholesaler, and retailer.	1790s	~100	South Asia, Mongolia, New Zealand, UK, and EU.	6
FC5 Wholesaler and online retailer of specialized fashion accessories including fashion bags, footwear, and fast fashion garments.	2000s	40	UK and EU, China, Korea, Turkey, and South Asia.	4
FC6 Online retailer and provider of all levels (basic, luxury and fast fashion) of fashion garments, footwear, and fashion accessories.	2000s	~2,700	UK and EU, South Asia, Asia Pacific Turkey, North America, Middle East, and Central Asia.	6

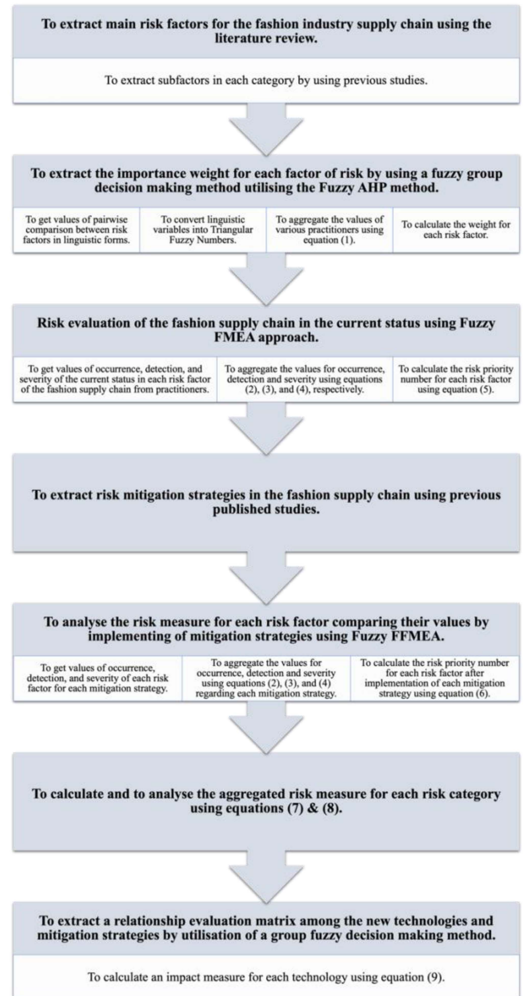

Fig. 1. Overall research method flowchart.

TABLE VI
DEFINITION OF THE PARAMETERS/VARIABLES USED IN THIS STUDY

$\tilde{a}^{g}_{ij}(l^{g}_{ij}, m^{g}_{ij}, n^{g}_{ij})$	is a TFN that shows how important is risk factor *I* comparing to the factor *j* by g^{th} participant ($\tilde{a}^{g}_{ij} = 1/\tilde{a}^{g}_{ij}$)
w_{ik}	Importance weight of risk factor *i* in category *k*
wr_k	Importance weight of risk category *k*
$\widetilde{OC}^{initial/s-g}_{ik}$	Occurrence of risk factor *i* in category *k* defined by the g^{th} participant (initial value/by implementing the s^{th} mitigation strategy)
$\widetilde{SE}^{initial/s-g}_{ik}$	Severity of risk factor *i* in category *k* defined by the g^{th} participant (initial value/by implementing the s^{th} mitigation strategy)
$\widetilde{DE}^{initial/s-g}_{ik}$	Detection of risk factor *i* in category *k* defined by the g^{th} participant (initial value/by implementing the s^{th} mitigation strategy)
$\widetilde{RPN}^{initial}_{ik}$	Initial (current) risk priority number of risk factor *i* in category *k*
$\widetilde{RPN}^{s}_{ik}$	Risk priority number of risk factor *i* in category *k* using the s^{th} mitigation strategy
$RPN^{initial/s}_{k}$	Total risk priority number value for the k^{th} risk category (initial/after implementation of the s^{th} mitigation strategy)
$\underline{RPN^{s}}$	Total risk priority number value (initial/after implementation of the s^{th} mitigation strategy)
$\widetilde{IM}^{t}_{s}$	Impact value of the t^{th} technology on the s^{th} risk mitigation strategy
$\widetilde{IM}^{t}$	Impact value of the t^{th} technology on risk mitigation strategies

vagueness, ensuring greater flexibility for the participants in their responses.

A hierarchical group fuzzy decision-making method was utilized to extract the main risk factors of the fashion industry to examine the strategies used to mitigate the extracted risk factors and, finally, to determine the most impactful technologies when proceeding with those strategies. It should be noted that the fuzzy group AHP has been used to evaluate and prioritize the importance of FSC risk factors. The fuzzy FMEA technique has been used to quantify the current risk status of the FSC as well as its expected value by adopting each mitigation strategy. The proposed hybrid method provides an opportunity to discover the impact of each mitigation strategy to improve the occurrence probability, severity, and detectability of each risk factor by considering the selected FSC decision-maker's opinions. Fig. 1 illustrates the applied research method for this study, whereas Fig. 2 presents the overall data collection scheme as well as its purpose.

All used parameters/variables considered in this research have been defined in Table VI.

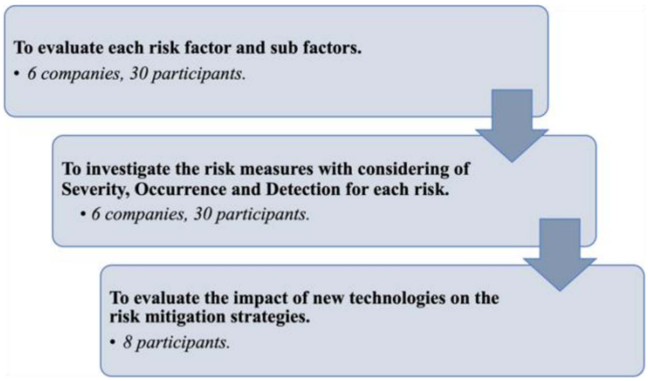

Fig. 2. Data collection scheme.

In this research, linguistic variables have been used to make sure that the practitioners in the FSC are able to provide more reliable answers to the designed questionnaire. Linguistic variables could be converted to a TFN by using the following equivalent table.

Equivalent Table			
Very Low (VVL)	1	1	1
Very Low (VL)	1	2	3
Low (L)	2	3	4
Medium Low (ML)	3	4	5
Medium (M)	4	5	6
Medium High (MH)	5	6	7
High (H)	6	7	8
Very High (VH)	7	8	9
Very Very High (VVH)	8	9	10
Extremely High (EH)	10	10	10

Then, the extracted TFN values from practitioners were integrated using (1). This calculated the geometric meaning among the received responses

$$\tilde{a}_{ij} = \left(\sqrt[g]{\prod_{g=1}^{G} l_{ij}^{g}},\ \sqrt[g]{\prod_{g=1}^{G} m_{ij}^{g}},\ \sqrt[g]{\prod_{g=1}^{G} n_{ij}^{g}} \right). \quad (1)$$

During the fuzzy-AHP method, an aggregated pairwise comparison table was determined to extract the weight of each risk factor from inside a category as well as the weight of each risk factor category (w_{ik} and wr_k)

$$\tilde{A} = \begin{bmatrix} (1,1,1) & \tilde{a}_{12} & \dots & \tilde{a}_{1n} \\ \tilde{a}_{21} & (1,1,1) & \dots & \tilde{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{a}_{n1} & \tilde{a}_{n2} & \dots & (1,1,1) \end{bmatrix}.$$

After determining the importance weight for each risk factor in the FSC, the risk measure was calculated for the current situation as well as its value after implementing a risk mitigation strategy using a fuzzy FMEA approach. To do so, a related questionnaire was developed, and we asked the practitioners to consider the risk severity, risk detection, and risk occurrence of a risk in the FSC. These were integrated using (2)–(4). Equation (2) calculates the aggregated fuzzy score for risk occurrence based on the scores provided by individual decision makers, while (3) and (4) determine the aggregated fuzzy scores for risk severity and risk detection, respectively

$$\widetilde{\mathrm{OC}}_{ik}^{\mathrm{initial}/s} = \left(\sqrt[g]{\prod_{g=1}^{G} l\left(\widetilde{\mathrm{OC}}_{ik}^{\mathrm{initial}/s-g}\right)},\right.$$
$$\left. \times \sqrt[g]{\prod_{g=1}^{G} m\left(\widetilde{\mathrm{OC}}_{ik}^{\mathrm{initial}/s-g}\right)},\ \sqrt[g]{\prod_{g=1}^{G} n\left(\widetilde{\mathrm{OC}}_{ik}^{\mathrm{initial}/s-g}\right)} \right). \quad (2)$$

The distributed survey included questions related to the occurrence probability of each risk factor using linguistic variables. A fuzzy equivalent of the values from the participants was aggregated using (2)

$$\widetilde{\mathrm{SE}}_{ik}^{\mathrm{initial}/s} = \left(\sqrt[g]{\prod_{g=1}^{G} l\left(\widetilde{\mathrm{SE}}_{ik}^{\mathrm{initial}/s-g}\right)},\right.$$
$$\left. \times \sqrt[g]{\prod_{g=1}^{G} m\left(\widetilde{\mathrm{SE}}_{ik}^{\mathrm{initial}/s-g}\right)},\ \sqrt[g]{\prod_{g=1}^{G} n\left(\widetilde{\mathrm{SE}}_{ik}^{\mathrm{initial}/s-g}\right)} \right). \quad (3)$$

Equation (3) also aggregates the fuzzy equivalent values on the severity of a risk factor according to the participants

$$\widetilde{\mathrm{DE}}_{ik}^{\mathrm{initial}/s} = \left(\sqrt[g]{\prod_{g=1}^{G} l\left(\widetilde{\mathrm{DE}}_{ik}^{\mathrm{initial}/s-g}\right)},\right.$$
$$\left. \times \sqrt[g]{\prod_{g=1}^{G} m\left(\widetilde{\mathrm{DE}}_{ik}^{\mathrm{initial}/s-g}\right)},\ \sqrt[g]{\prod_{g=1}^{G} n\left(\widetilde{\mathrm{DE}}_{ik}^{\mathrm{initial}/s-g}\right)} \right). \quad (4)$$

The fuzzy equivalent values for the detection of each risk factor from the participants were aggregated using (4).

Then, the risk priority number (RPN) for each risk factor in the current status was calculated using (5). Moreover, its value was calculated for the adoption of each risk mitigation strategy using (6)

$$\widetilde{\mathrm{RPN}}_{ik}^{\mathrm{initial}} = \widetilde{\mathrm{OC}}_{ik}^{\mathrm{initial}} \otimes \widetilde{\mathrm{SE}}_{ik}^{\mathrm{initial}} \otimes \widetilde{\mathrm{DE}}_{ik}^{\mathrm{initial}} = \left(l\left(\widetilde{\mathrm{OC}}_{ik}^{\mathrm{initial}}\right) \right.$$
$$* l\left(\widetilde{\mathrm{SE}}_{ik}^{\mathrm{initial}}\right) * l\left(\widetilde{\mathrm{DE}}_{ik}^{\mathrm{initial}}\right),\ m\left(\widetilde{\mathrm{OC}}_{ik}^{\mathrm{initial}}\right) * m\left(\widetilde{\mathrm{SE}}_{ik}^{\mathrm{initial}}\right)$$
$$\left. *m\left(\widetilde{\mathrm{DE}}_{ik}^{\mathrm{initial}}\right), n\left(\widetilde{\mathrm{OC}}_{ik}^{\mathrm{initial}}\right) * n\left(\widetilde{\mathrm{SE}}_{ik}^{\mathrm{initial}}\right) * n\left(\widetilde{\mathrm{DE}}_{ik}^{\mathrm{initial}}\right) \right) \quad (5)$$

$$\widetilde{\mathrm{RPN}}_{ik}^{s} = \widetilde{\mathrm{OC}}_{ik}^{s} \otimes \widetilde{\mathrm{SE}}_{ik}^{s} \otimes \widetilde{\mathrm{DE}}_{ik}^{s} = \left(l\left(\widetilde{\mathrm{OC}}_{ik}^{s}\right) *l\left(\widetilde{\mathrm{SE}}_{ik}^{s}\right) \right.$$
$$*l\left(\widetilde{\mathrm{DE}}_{ik}^{s}\right),\ m\left(\widetilde{\mathrm{OC}}_{ik}^{s}\right) *m\left(\widetilde{\mathrm{SE}}_{ik}^{s}\right) *m\left(\widetilde{\mathrm{DE}}_{ik}^{s}\right),$$
$$\left. n\left(\widetilde{\mathrm{OC}}_{ik}^{s}\right) *n\left(\widetilde{\mathrm{SE}}_{ik}^{s}\right) *n\left(\widetilde{\mathrm{DE}}_{ik}^{s}\right) \right). \quad (6)$$

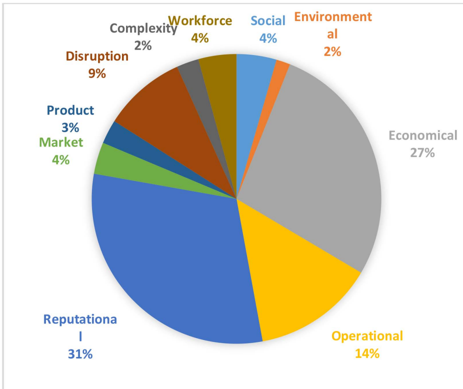

Fig. 3. Importance of supply chain risks in the fashion industry.

The aggregated RPN for each risk category and the total value of RPN considering all risks in the FSC were calculated using (7) and (8), respectively

$$\mathrm{RPN}_k^{\mathrm{initial}/s} = \sum_{i=1}^{|k_i|} w_{ik} * \mathrm{RPN}_{ik}^{\mathrm{initial}/s} \tag{7}$$

$$\mathrm{RPN}^{\mathrm{initial}/s} = \sum_{k=1}^{|K|} wr_k * \mathrm{RPN}_k^{\mathrm{initial}/s}. \tag{8}$$

After determining the weights for each risk factor and extracting the risk priority number by adopting a risk mitigation strategy, we focused on technology implementation in the fashion industry to analyze how each technology impacts the mitigation strategies. Relevant questionnaires were distributed among practitioners and then the impact measure was calculated using the following equation:

$$\widetilde{\mathrm{IM}}^t = \left(\sum_{s=1}^{|S|} \sqrt[g]{\prod_{g=1}^{G} l\left(\widetilde{\mathrm{IM}}_s^t\right)},\ \sum_{s=1}^{|S|} \sqrt[g]{\prod_{g=1}^{G} m\left(\widetilde{\mathrm{IM}}_s^t\right)},\ \sum_{s=1}^{|S|} \sqrt[g]{\prod_{g=1}^{G} n\left(\widetilde{\mathrm{IM}}_s^t\right)} \right). \tag{9}$$

TABLE VII
IMPORTANT RISK FACTORS WITH THEIR IMPORTANCE RATE EXTRACTED BY A FUZZY-AHP METHOD

Important Factors		
Social	Health and safety issues in factories.	49%
	Workforce redundancy and employment risks.	27%
Environmental	Pollution (Water pollution, carbon emissions, packaging, etc.).	18%
	High use of chemicals in products.	60%
Economical	High operating costs.	31%
	Price competition.	30%
Operational	Lack of real-time information sharing and communication.	17%
	Capacity and technological risks (innovations for automation).	21%
Reputational	Due to lack of supply chain visibility and control.	31%
	Product damage and quality issues.	28%
Market	Dynamic, complex, unpredictable, and volatile.	21%
	Greater bargaining power of retailers.	45%
Product	On-trend product availability (Impulse buying).	37%
	Poor demand forecasting.	33%
Disruption	Increased frequency and longer recovery time.	31%
	Dependency risks.	26%
Complexity	Cultural issues.	15%
	Design complexities.	49%
Workforce	Lack of knowledge, skills and capabilities required for fashion business.	55%
	Aging workforce and lack of young generation's interest in manufacturing.	45%

Fig. 4. Aggregated RPN for mitigation strategies.

IV. FINDINGS

After using the fuzzy-AHP method, the risk categories were evaluated. The extracted final weight of each risk factor in the FSC has been illustrated in Fig. 3.

The most important risk factors in each risk category have been reported in Table VII.

By implementing the FMEA approach, we were able to calculate the RPN for each strategy and the results have been reported in Table VIII. As an example, the results show that, by the implementation of the sourcing strategy, social risk will not be mitigated as its risk value remains unchanged (213.1). However, it will help to reduce the environmental risk from 332 to 308. The mentioned table illustrates how each strategy will have an impact on reducing each risk factor. According to the reported results in Table VIII, it was concluded that "Creating a risk management culture" will be a more appropriate strategy to be used related to the FSC because of achieving the lowest RPN value (128.8).

The aggregated RPN regarding applying mitigation strategies has been illustrated in Fig. 4. It also illustrates and compares the RPN values of various strategies. It is evident that the strategy with the lowest value will be the best strategy to be applied.

After evaluation of each technology, it was realized that two technologies are more impactful regarding mitigation strategies. Fig. 5 illustrates their impact on the strategies.

Finally, the impact measures for different technologies have been summarized in Table IX, as well as Fig. 6. The higher values in Table IX show more impact on the mitigation strategy. The bold results show the most effective technology for each

TABLE VIII
SUMMARIZED AGGREGATED RPN VALUES FOR EACH STRATEGY

Risk Factors	Importance Weight		Initial	Avoid, transfer and share	Sourcing strategy (Multiple, Local)	Buffers and Safety Stock	planning and Decision Making	Workforce and Management Development	Communication and Information Sharing	Building Relationships	Designing a Resilient System/SC	Supply Chain Redesign for flexibility, Agility, and Responsiveness	Using Technology	Audits, Inspection, and Monitoring	Creating a Risk Management Culture	Insurance and Hedging	Resource Sharing
Social	0.045	Average RPN	213.1	174.7	213.2	215.3	155.9	192.2	119.7	116.6	103.6	163.1	170.3	174.9	**84.9**	192.8	134.1
		Weighted Average RPN	9.5	7.8	9.5	9.6	7.0	8.6	5.3	5.2	4.6	7.3	7.6	7.8	**3.8**	8.6	6.0
Environmental	0.016	Average RPN	332.4	275.9	308.2	278.3	128.0	292.7	139.2	117.7	153.4	157.4	156.3	115.0	131.5	110.7	**103.3**
		Weighted Average RPN	5.2	4.3	4.8	4.4	2.0	4.6	2.2	1.8	2.4	2.5	2.4	1.8	2.1	1.7	**1.6**
Economical	0.275	Average RPN	299.5	387.3	288.3	266.3	229.5	159.6	140.0	147.4	136.4	119.5	164.9	145.5	**117.6**	149.1	141.6
		Weighted Average RPN	82.3	106.4	79.2	73.2	63.1	43.9	38.5	40.5	37.5	32.9	45.3	40.0	**32.3**	41.0	38.9
Operational	0.136	Average RPN	438.5	421.1	414.2	369.4	346.9	334.9	254.9	256.1	258.1	232.9	320.7	311.8	**133.8**	298.0	175.5
		Weighted Average RPN	59.6	57.2	56.3	50.2	47.1	45.5	34.6	34.8	35.1	31.7	43.6	42.4	**18.2**	40.5	23.9
Reputational	0.307	Average RPN	283.4	277.8	329.4	263.2	226.7	259.2	205.1	144.2	**122.9**	148.0	196.8	218.9	153.3	197.0	138.0
		Weighted Average RPN	87.0	85.2	101.1	80.8	69.6	79.5	62.9	44.3	**37.7**	45.4	60.4	67.2	47.1	60.5	42.4
Market	0.035	Average RPN	372.3	334.9	322.0	260.5	232.0	250.5	173.3	162.4	137.6	136.1	188.1	252.8	**117.6**	213.6	124.3
		Weighted Average RPN	13.2	11.9	11.4	9.2	8.2	8.9	6.1	5.8	4.9	4.8	6.7	9.0	**4.2**	7.6	4.4
Product	0.027	Average RPN	198.2	232.5	203.2	230.1	180.5	177.6	122.5	114.9	108.3	**99.1**	158.9	214.8	112.9	165.7	112.9
		Weighted Average RPN	5.3	6.3	5.5	6.2	4.9	4.8	3.3	3.1	2.9	**2.7**	4.3	5.8	3.0	4.5	3.0
Disruption	0.093	Average RPN	247.4	205.1	174.7	205.8	213.6	198.4	209.1	99.6	129.8	143.6	255.7	247.8	**94.7**	236.7	140.7
		Weighted Average RPN	22.9	19.0	16.2	19.0	19.8	18.4	19.3	9.2	12.0	13.3	23.7	22.9	**8.8**	21.9	13.0
Complexity	0.025	Average RPN	385.9	307.7	249.8	289.2	232.1	229.6	146.9	127.4	114.7	130.2	209.6	185.6	**93.5**	193.1	105.9
		Weighted Average RPN	9.6	7.6	6.2	7.2	5.8	5.7	3.6	3.2	2.8	3.2	5.2	4.6	**2.3**	4.8	2.6
Workforce	0.042	Average RPN	464.2	395.7	372.3	258.3	271.1	267.3	220.3	182.1	147.5	162.5	185.9	201.0	166.6	205.6	**132.5**
		Weighted Average RPN	19.7	16.8	15.8	11.0	11.5	11.4	9.4	7.7	6.3	6.9	7.9	8.5	7.1	8.7	**5.6**
		Total RPN	314.3	322.6	306.0	270.7	238.9	231.1	185.3	155.6	146.2	150.6	207.0	209.9	**128.8**	199.7	141.4

TABLE IX
SUMMARY OF THE MOST IMPACTFUL TECHNOLOGIES IN THE MITIGATION STRATEGIES

Technology	Mitigation Strategy														
	Avoid, Transfer, and Share	Sourcing Strategy (Multiple, Local)	Buffers and Safety Stock	Planning and Decision Making	Workforce and Management Development	Communication and Information Sharing	Building Relationships	Designing a Resilient System/SC	Supply Chain Redesign for Flexibility, Agility, and Responsiveness	Using Technology	Audits, Inspection, and Monitoring	Creating a Risk Management Culture	Insurance and Hedging	Resource Sharing	Aggregated Impact
RFID	6.27	6.04	5.82	6.85	4.92	7.34	4.43	5.81	6.30	6.84	5.04	4.60	3.72	6.07	80.06
Blockchain	5.91	5.87	5.43	7.06	4.77	6.83	4.64	6.14	6.92	7.95	5.53	5.79	4.44	5.89	83.17
IoTs	5.86	5.66	5.43	7.10	5.84	7.10	4.70	6.28	6.72	7.46	5.14	5.43	4.04	6.21	82.98
Robotics	3.56	3.17	3.86	3.97	4.05	4.47	2.95	4.19	4.60	6.12	3.22	4.37	3.30	4.77	56.61
AI	6.48	6.72	6.46	7.83	7.10	8.34	6.19	**7.33**	**8.19**	**8.56**	**6.46**	5.66	**5.33**	6.98	**97.64**
ERP Systems	5.21	5.28	5.19	6.09	5.48	6.36	4.57	5.23	5.48	5.71	4.33	4.91	4.47	5.98	74.28
Geo-coded Tracking Systems/GPS	5.09	5.51	5.04	5.69	4.08	5.51	3.99	4.81	5.48	5.48	4.41	5.02	3.99	4.84	68.93
Bar Coding Technology	5.53	5.28	5.96	6.59	4.88	6.18	4.53	5.55	5.84	5.66	5.18	5.16	4.02	5.28	75.66
ICT/EDI	**7.07**	**7.08**	**6.46**	**8.12**	**7.10**	**8.97**	**7.17**	7.10	7.22	7.74	6.05	**7.02**	5.11	**7.30**	**99.51**
Aggregated Impact	50.98	50.60	49.64	59.30	48.22	61.09	43.20	52.45	56.74	61.53	45.37	47.97	38.42	53.32	

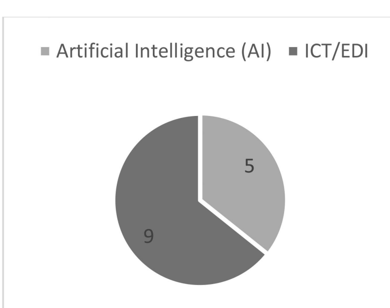

Fig. 5. Summary of most impactful technologies in the mitigation strategies.

mitigation strategy. As an example, AI and information and communication technology (ICT) are the most effective technologies for "Designing a resilient system" and "Building relationships," with bolded and underlined values of 7.33 and 7.17, respectively. Moreover, there are more underlined values for AI and ICT in the table, and this confirms that both of the mentioned technologies are more effective in most mitigation strategies.

To consider how the changing of the risk factors' weights may impact on the FSCs risk mitigation strategies, a sensitivity analysis approach was designed [68]. For this purpose, we conducted a designed analysis, including 30 experiments,

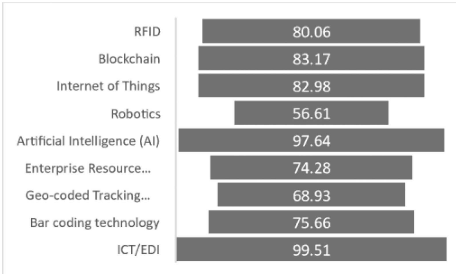

Fig. 6. Total impact of technologies in the reduction of risks in the FSC.

to examine the risk factors. The weights for each factor were increased by multiplying them by 2, 3, and 4. When considering a new weight for each factor, the weights of the other factors were normalized accordingly.

Then, the RPN was calculated for each mitigation strategy, considering the new weights. It was realized that, in most cases (90%), "Creating a risk management culture" is the most effective mitigation strategy among others. However, in only 10% of cases was "Designing a resilient supply chain" determined to be an effective risk mitigation strategy. This shows that even if the weight of the risk factors changes, it is more reasonable to create a risk management culture to mitigate the risks more efficiently. In another analysis, we also considered the variance of the RPN values for each mitigation strategy among the changes in weight. It was realized that "avoid, transfer, and share" is the most sensitive strategy to the risk factors' weights with a variance of 567. The following two strategies have the least sensitivity to changes in risk factor weights with variance values of 15 and 56, respectively, "resource sharing" and "creating a risk management culture." The results of the sensitivity analysis are reported in Appendix B.

V. Discussion

A. Importance of Risks and Their Subfactors

Social Risk Category: Health and safety risks (49%) were reported as the most critical, followed by workforce redundancy and employment risks (27%). The fashion industry is known for increased health and safety issues [77], [82], leading to a loss of workers' lives, such as in the Rana Plaza incident in Bangladesh [42]. The empirical research also reported the inhuman working conditions and practices contributing to health and safety issues, such as an unhealthy and unhygienic working environment, longer working hours, forced and unpaid work, and modern slavery issues [31], [35], [42]. These issues are more acute for the U.K. fashion industry due to its manufacturing outsourcing, lack of visibility and control, and the use of subcontracting practices at the supplier locations [81], [82]. Our findings also indicated the importance of workforce redundancy and employment risks in the U.K. fashion industry, which are due to the decline of the industry and reliance on cheap imports [95], [48], [81]. Increasing energy and operating costs and the ability of developing country suppliers to meet the unpredictable demand with shorter production runs, including initiatives of capacity, capability, and design development, have enabled them to offer more stylish and cost-effective products, consequently making U.K. fashion production less attractive [81]. This finding supports the extant empirical research [31], [35], [41], [48], [77], [81], [82], [95] and also makes contributions by highlighting the contextual peculiarities regarding social risk subfactors, such as health and safety, workforce redundancy, and employment risks in the U.K. fashion industry.

Environmental Risk Category: The high use of chemicals in products (60%) was considered to be the most critical, followed by pollution (water pollution, carbon emissions, and packaging; 18%). Fashion production makes heavy use of chemicals, which contaminate water and pollute waterways, causing health and safety issues, spreading diseases, and heavily impacting marine life and seafood [35]. The globalized fashion industry also causes a high amount of CO_2 emissions due to transportation and the waste from packaging, damaged and poor-quality products, and returns [17], [34], [41], [97]. The geographical dispersion of fashion manufacturing and retail also leads to the use of intermodal transportation modes and multiple facility locations, thus contributing to environmental degradation and polluting natural resources during transit and within and across facilities. The fashion management literature highlights various environmental issues. However, to date, it has been unknown what the most important environmental risk subfactors are in the categories that worry the U.K. fashion industry the most. This research supports the extant empirical research, which has highlighted the above issues [17], [34], [35], [41], [97]. Furthermore, this research found that the use of chemicals and pollution is regarded as the most critical environmental risk subfactor by the participating firms.

Economic Category: High operating costs were considered to be the most important risk (31%), followed by price competition (30%). The U.K. fashion industry is experiencing high operating costs due to a lack of raw material availability, higher energy costs, living wages, and a lack of availability of a skilled workforce [48], [81], [95]. Most of the industry has declined due to fashion retail's reliance on outsourcing and the outsourcing specifically of its offshore manufacturing to developing countries, such as Bangladesh and China. The remaining U.K. fashion manufacturers find it difficult to compete against cheap imports due to the high operating costs in the U.K. and severe price competition within the global fashion industry [81]. Furthermore, advancements in ICTs, especially social media, mean that consumers are better informed about fashion product availability and choice, and are able to buy fashion products at the price, place, and quality they want to buy [82]. Thus, this research supports the extant empirical research that highlights the economic issues in the fashion industry [48], [81], [82], [95], as well as making original contributions by highlighting that high operating costs and price competition are the most important subfactors in the economic risk category in the U.K. fashion industry.

Operational Risk Category: Capacity and technological risks (innovations for automation) were considered to be most important (21%), followed by a lack of real-time information sharing and communication (17%). The abolition of the multi-fiber agreement has allowed unrestricted garments' imports in the U.K. Furthermore, offshore manufacturing and the reliance on an open market and subcontractors have led to a capacity decline in U.K. fashion manufacturing in almost all operational areas [48], [95]. Consequently, the remaining firms in the U.K. fashion manufacturing industry cannot innovate and grow. The remaining fashion manufacturing firms face the acute problems of a stagnant organizational culture, outdated technology, and struggling to attract a new and young workforce, developing skills, and obsolete working and managerial practices [81]. The U.K. government and industry lobby groups are trying to revive and rebuild fashion manufacturing clusters, encouraging fashion consumers with made-in-U.K. and sustainable product-related campaigns. Rafi-ul-Shan et al. [81] explored how U.K. fashion companies have engaged in coopetitive relationships to mitigate their capacity and technological risks. FSCs are now longer and more complex [83]. Fashion retailers' reliance on imports from China and Bangladesh makes it longer and negatively impacts operational visibility and control [81]. Consequently, compromising real-time information sharing and communication with supply chain partners is essential to identify and manage risks and to be able to provide a quick response [23], [59], [77]. Thus, this research supports the extant empirical research that highlights the above-highlighted operations' risks in the fashion industry [23], [48], [62], [77], [81], [83], [95] while also making original contributions by highlighting that the capacity and technological risks and real-time information sharing and communication are the most important subfactors in the operational risk category in the U.K. fashion industry.

Reputational Risk Category: The lack of supply chain visibility and control risk subfactors was considered to be the most important (31%), followed by product damage and quality issues (28%). The disclosure of unethical and unsustainable practices in the fashion industry, such as child and forced labor, and natural resource consumption and depletion by the media and NGOs has negatively impacted the brand image of leading global fashion brands [77]. Brand image is known to be a strategic and competitive tool to compete in a saturated, consumer facing, highly competitive, and dynamically changing fashion industry [82]. Suppliers in developing countries have reported that their buyers take on social sustainability initiatives to protect their reputation only and to avoid bad publicity instead of internalizing the idea of a socially sustainable supply chain [43]. The extant empirical research has reported reputational risks due to a lack of FSCs visibility and control, as well as its global and complex nature, and product and demand characteristics [77], [82]. Unethical practices, environmental and social issues, subcontracting work, and other issues are well reported in the FSC literature, indicating the vulnerabilities of reputation risk [31], [42], [77]. Longer lead times, supply chain complexity, and multiple handling requirements also lead to product damage and quality issues [23], [62]. Thus, this research supports the extant empirical research that highlights the reputational risks in the fashion industry [31], [42], [43], [77], [82], as well as making original contributions by highlighting that the lack of FSC visibility and control and product damage and quality issues are the most important subfactors in the operational risk category in the U.K. fashion industry.

Market Risk Category: The greater bargaining power of retailers (45%) was considered to be the most important, followed by the dynamic, complex, unpredictable, and volatile nature of the fashion market (21%). Fashion retailers are considered to be the focal firms in FSC with a greater bargaining power and ability to influence the practices and behaviors of their network partners [82]. A high bargaining power enables fashion retailers to transfer price, cost, and design development to the upstream levels of their supply chain [81]. The U.K. fashion industry lacks knowledge and expertise in fast fashion manufacturing but it is specialized and known for its quality and luxury fashion manufacturing [48], [81], [95]. Thus, a volatile and unpredictable demand, and dynamic and complex FSCs have been proved to be problematic for the U.K. fashion industry, causing market risks [81]. Due to the short lead time, midseason buying, and requirements for a quick response, this has created a hope for more balanced asymmetrical relationships and more of a power balance between retailers and suppliers [96]. However, the empirical research has reported that retailers have not only maintained their bargaining power but also how the availability of cheap suppliers and subcontractors has further enabled retailers to squeeze the margins and enhance their bargaining power [81], [82], [96]. Therefore, the authors in [48] and [95] have argued that the U.K. fashion industry can find its place in an innovative and luxury marketplace. Thus, this research supports the extant empirical research that highlights the above-highlighted market risks in the fashion industry [48], [81], [82], [96] while also making original contributions by investigating how the high bargaining power of the retailer and the dynamic, volatile, and unpredictable nature of the fashion market are the most important subfactors in the market risk category in the U.K. fashion industry.

Product Risk Category: The on-trend product availability was considered to be the most important (37%), followed by poor demand forecasting (33%). The fashion characteristics of a short life cycle, volatile and unpredictable demand, impulse buying, and elements of style and trend imply that demand forecasts are not only hard to get correct but are also inappropriate in the fashion industry [23]. Therefore, the empirical research has necessitated the use of advanced innovative digital technologies for communication, information sharing, collaboration, and integration within the organization and across its supply chain partners [82], [92]. Seamless organizational and supply chain structures enabled by modern digital, ICTs enhance the capabilities that are essential to compete in the fashion market, including proactively identifying trends, ensuring on-trend product availability, fulfilling consumer demands, and facilitating impulse buying [92]. Thus, this research supports extant empirical research that highlights the above-highlighted fashion product risks [23], [82], [92] while also making original contributions by investigating how on-trend product availability and poor demand forecasting are the most important subfactors in the fashion product risk category in the U.K. fashion industry.

Disruption Risk Category: Increased frequency and a longer recovery time were considered to be the most important (31%), followed by dependency risks (26%). The risk volatility index proposed by Christopher and Holweg [22] reported that businesses are experiencing an increased number of disruptions and are taking a much longer time to recover from those disruptions. This is due to their existing business structures and philosophies, which are based on stability assumptions and lean and cost efficiencies. Similarly, the risk management literature has advocated the use of multiple sourcing to remain flexible in order to respond to the unpredictable and volatile demand in the fashion industry and to reduce dependency risks [23]. Rafi-ul-Shan et al. [81] reported that U.K. fashion companies are engaged in a capacity-sharing process to reduce dependency risks. Other reasons for the disruptions in the FSC are due to ongoing sustainability and ethical issues, poor quality products, the poor logistics and distribution infrastructure, the inability to react quickly, and longer lead times, including a lack of visibility, control, integration, information sharing, and communication within and across FSCs [31], [35], [42]. Thus, this research supports the extant empirical research that highlights the above-highlighted fashion disruption risks [22], [23], [31], [35], [42], [81], as well as making original contributions by investigating how increased frequency and longer recovery times and dependency risks are the most important subfactors in the fashion disruptions risk category in the U.K. fashion industry.

Complexity Risk Category: Design complexities are considered to be the most important (49%), followed by cultural issues (15%). Culture has been discussed from multiple perspectives in the fashion industry because of its importance as a part of a quick response [32], being agile and reactive to fashion trends and the use of modern technologies [82], [92] and understanding cultural issues in the context of product design [23], [31]. Our results also show that the U.K. fashion industry is concerned with design complexities, which might be due to mixed production, a lack of skills, and capabilities and resources [81], and being unable to respond to changing consumer tastes and preferences by being rigid and inflexible when needing to make quick changes in design and product development [23]. The fragmented, lack of vertical integration, and labor-intensive nature of the industry implies that different operations being performed in multiple geographic regions add further complexities for the focal firm. A more collaborative approach to design development and the simplification and decentralization of operational decision making is suggested to minimize the complexity risks in FSCs [31], [32], [62]. Thus, this research supports the extant empirical research that highlights the above-highlighted fashion complexity risks [23], [31], [32], [62], [81], [92], as well as making original contributions by investigating how design complexity and cultural issues are the most important subfactors in the fashion complexity risk category in the U.K. fashion industry.

Workforce Category: A lack of knowledge, skills, and the capabilities required in the fashion business was considered to be the most important (55%), followed by the aging workforce and a lack of interest among the younger generations in manufacturing (45%). The fashion and apparel industry is known to be labor intensive and most of the critical operations are manually performed at different tiers in the FSC [31]. Therefore, the availability of a skilled workforce is vital to produce quality products, satisfy consumer demand, and provide better customer service. The outsourcing and offshore manufacturing of fashion by the U.K. retailer has also negatively been impacted by the availability of a skilled workforce for the U.K. fashion industry [48], [81], [96]. Rafi-ul-Shan et al. [81] reported on the shared use of the workforce within fashion companies and the initiatives undertaken for skill development. However, they suggested a more collaborative industry and government, including an educational institution dialog and approaches to attract the young generation into the manufacturing sector. Thus, this research supports the extant empirical research that highlights the above-highlighted fashion workforce risks [31], [48], [81], [96], as well as going on to make original contributions by investigating how the lack of knowledge, skills, and capabilities, as well as the aging workforce and lack of the younger generations' interest, are the most important subfactors in the fashion workforce risk category in the U.K. fashion industry.

B. Risk Mitigation Strategies

Creating a supply chain management culture is suggested to be the best strategy to mitigate FSCs risks (social, economic, operational, market, disruptions, and complexity). Christopher et al. [23] highlighted the importance of culture to design resilient supply chains by creating supply chain continuity teams, considering risk in decision making, and making it a board-level responsibility. Similarly, Christopher and Holweg [22] proposed changing the organizational culture as a part of supply risk management. Due to fashion product and demand characteristics, the importance of an agile and responsive culture in order to compete in volatile and unpredictable marketplaces, such as fashion, is also highlighted by the authors in [82] and [92]. Similarly, Perry et al. [77] highlighted the importance of culture in relation to sustainability and ethics in FSCs. Rafi-ul-Shan et al. [81] discussed the importance of culture for management commitment, leadership, information sharing, and communication and relationship development as a part of FSC risk management.

Resource sharing has been suggested as the most effective risk mitigation strategy for environmental and workforce-related risks. Rafi-ul-Shan et al. [81] reported on the resource-sharing practices of U.K. fashion firms, such as knowledge, workforce, and logistics and distributions resource sharing, developing innovation capabilities, training and skills development, risk reduction, and cost minimization. De Brito et al. [26] highlighted the importance of resource sharing in managing transportation issues and for clean and environmental sustainability purposes. The extant empirical research has reported on most of the reputational risks due to sustainability and ethical misconduct that remain invisible and out of control in the upstream levels of FSCs [59], [61]. Globalization and the complexity of FSC operations further make it difficult for focal firms to ensure monitoring and control, necessitating a resilient design in FSCs to mitigate reputational risks [59]. Resilient design has been reported to be a useful tool to bounce back from disruptions with minimal consequences and in a short timescale [22], [59]. Similarly, empirical research has supported the idea of flexibility, agility, and responsiveness [23], [82] as a part of responding to the latest trends, styles to make the necessary product, or operational changes in FSCs. Thus, a flexible, agile, and responsive supply chain will enable fashion firms to manage product-related risks [92]. Thus, this research supports the extant empirical research that has reported the above-highlighted risk mitigation strategies [22], [23], [26], [31], [32], [61], [62], [77], [81], [82], [92], making original contributions by investigating the organizational culture, resource sharing, and resilient design for greater flexibility, agility, and responsiveness as the most important fashion risk mitigation strategies in the U.K. fashion industry.

C. Technological Impact on Risk Mitigation Strategies

Empirical research has reported the use of numerous innovative technologies in the fashion industry [14], [25], [90], [104]. However, our results show that ICT and AI are the most appropriate technologies with the highest potential to increase the impact and robustness of FSC risk mitigation strategies. The results show that AI can facilitate the designing of resilient systems, supply chain redesign for flexibility, enhance agility and responsiveness, facilitates, and increase the robustness of audits, inspections and monitoring, insurance, and hedging. The empirical research has reported on the numerous benefits of AIs application in the fashion industry, for example, analyzing fashion consumer tastes and preferences, size measurement and fitting, enhancing the customer shopping experience, reducing returns, and ensuring sustainability [90]. In contrast, ICT facilitates decision making for the purpose of risk avoidance, risk transfer, and sharing risks with the supply chain partners specifically about sourcing strategy and safety stock, workforce and management development, communication, and information sharing, creating a risk management culture and engaging in resource sharing. Braglia et al. [14] hold that ICT enables supply chains to provide superior customer service, ensure product quality, implement accurate distribution, use inventory control tools, and provide accurate demand forecasting. Bertola and Teunissen [11] have maintained that ICT has enabled fast fashion to share real-time information sharing and transformed fashion cycles based on quick responses and a semiplanned production based on real-time data from retail channels. Although empirical research has made enormous contributions in the field of technology and fashion [11], [14], [90], this study has contributed to the knowledge domain by investigating how AI and ICT are the most appropriate technologies for enhancing the effectiveness and robustness of fashion risk mitigation strategies in the U.K. fashion industry.

VI. Conclusion

Fashion products are characterized as having a short life cycle, having an unpredictable and volatile demand, and a high degree of impulse buying [23], [64]. Fast fashion retailers offer rapidly changing collections of low-cost and trend-led garments by translating street styles into new collections at highly competitive prices to encourage consumers to engage in fashion buying [9]. Thus, the success of a fashion retailer depends on being proactive in order to predict and identify trends and being highly responsive to bringing on-trend fashion items to retail shelves to avoid markdowns and financial losses [82]. The FSC characteristics of agility and responsiveness to reduce lead times have enabled fashion retailers to gain a competitive advantage but they have also created various risks, including operational, ethical, environmental, and social issues at different tiers in the supply chains [59], [77].

The emerging innovative technologies, including new and emerging forms of data from these technologies, have presented enormous opportunities for the supply chain to enhance their competencies and build capabilities for sensing and seizing market opportunities and enabling proactive and well-informed decision making [33], [78]. The application of innovative digital technologies in the supply chain management discipline has positively impacted operational performance by increasing customer experience, speed, and efficiency [90]. Emerging and new forms of data, including information sharing and communication technologies, enable organizations to collect, analyze, and store diverse data on risk and disruptions to make SCRM-related informed decisions [40], [78]. Leading fashion brands integrate innovative emerging technologies, such as wearables, virtual, robots, and augmented and mixed reality for a more inclusive, convenient, and sustained in-store and online customer experience [90]. However, the use of innovative emerging technologies in the fashion industry also faces challenges due to the growing concerns regarding consumer privacy and trust. Similarly, a lack of top management commitment, the availability of resources and capabilities, organizational culture, technology standards, and the varied interests of FSC network partners also present challenges related to the use of emerging innovative technologies in FSCs [14], [26], [90], [104].

In this article, we adopted a structured review of the extant empirical research to identify fashion risks, the relevant subfactors, and mitigation strategies. Subsequently, the types and uses of emerging innovative digital technologies in FSCs have also been identified. This structured review of empirical research was based on the article of Denyer and Tranfield [27] and similar approaches in order to explore research advancements, as applied by Rafi-ul-Shan et al. [59], [82] in the fashion industry. A review of the extant empirical research was followed by the application of a fuzzy group decision-making approach, which utilized fuzzy-AHP and fuzzy FMEA methodologies to quantify the practitioners' thoughts. A questionnaire, including three parts, was distributed among 30 practitioners in six U.K. fashion companies. The implemented structured methodology helped us to better understand the feelings and responses of practitioners in the fashion industry on the risk factors/subfactors, mitigation strategies, and the role of technologies to enhance the robustness of fashion risk mitigation strategies.

This research found that practitioners value reputational risk more, followed by economic risk. The reputation of a fashion brand is considered to be a main competitive element and a driving force to attract and retain customers [15], [17], [35], [77]. Similarly, economic risks are also considered important due to the operating costs and increasing price competition in the sector [35], [42], [59], [77]. In contrast, the fashion sector is criticized due to its environmental impact [41], [59], [64], [81], [82]. However, this study found that the respondents from the participating firms considered environmental risk to be less critical. Similarly, operational risk [34], [41], [64], [65] and disruption risk [62], [81], [82] have taken comparatively more priority over the social [35], [59], [77], workforce [62], [95],

[96], complexity [41], [64], [65], product [28], [34], [64], [65], and market-related risks [34], [41], [64].

The FSC risk management literature reports that there are various mitigation strategies to mitigate fashion risks [23], [28], [34], [59]. This study found that fashion practitioners from the participating firms have highlighted creating a risk management culture as the most effective risk mitigation strategy. This finding supports the scholarly research in the FSC literature, which argues that risk management culture helps to create the realization that risks exist, enabling subsequent prioritization and mitigation strategies [22], [23], [28], [34], [41]. The importance of risk management culture is also highlighted in the supply chain literature in the creation of resilient supply chains [88]. This study also supports resource sharing as an important mitigation strategy for fashion risk management. Rafi-ul-Shan et al. [81] highlighted that the FSC shares transportation, distribution, warehouse, and even workforce sources to manage risks, as well as cooperate and compete. The findings are also differentiated from the extant empirical research that proposes fashion risk mitigation strategies of risk avoidance, risk transfer, and risk sharing, including multiple souring, safety stock planning and decision making, and workforce management, as the participants of this study believe that designing resilient, flexible, agile, and responsive systems with increased levels of communication and information sharing with the help of emerging innovative technologies are more robust mitigations' strategies in fashion risk management.

This study then evaluated the effectiveness of emerging innovative technologies in the already examined risk mitigation strategies. The findings of this research suggest that fashion practitioners believe that ICTs and AI can enhance the robustness and effectiveness of risk mitigation strategies. On the one hand, communication technologies help staff to be proactive through early warning systems and gathering intelligence and, on the other hand, AI helps by enabling the supply chain network partners to detect and prevent risks through real-time monitoring, tracking, and traceability. Fashion research has reported on the numerous benefits of AI regarding improving the customer in-store experience in terms of size and fit leading to a reduction in return. However, this study investigated the role of AI from an FSC practitioner's point of view. Similarly, AI helps FSCs optimize their operations for better routing and transportation to reduce the lead time, which, consequently, helps to achieve better customer service and capture the on-time demand. The fashion literature has also reported on the benefits of AI in terms of increasing visibility and control, better and accurate forecasting, and material and supplier management. The practitioners who participated in this study also realize that the effectiveness of existing risk mitigation strategies will be further improved by emerging technologies, such as blockchain and IoT. In contrast, commonly broadcasted fashion technologies, such as robotics, enterprise resource planning (ERP), and bar codes, have been suggested as less robust by fashion practitioners.

The findings of this research are valuable for managers in the participating case companies and, possibly, other firms in the industry that represent similar characteristics as participating companies. For example, this research highlighted the key risk factors and subfactors that will be instrumental in broadening the managerial understanding of the nature of risk and the overall risk profile, consequently enabling them to target the right areas for risk management purposes. The highlighted risk mitigation strategies can be used as a benchmark to mitigate fashion risks. Finally, this research will enable managers to understand the most important risks in their industry, as well as the corresponding mitigation strategies and emerging innovative digital technologies, all of which can enhance the effectiveness and robustness of fashion risk mitigation strategies.

Future research can adopt inductive and exploratory qualitative research to explore and gain insights regarding the importance of risk factors, mitigation strategies, and the use of emerging technologies. Exploratory research will enable the exploration of the current phenomena in a real context that will also provide opportunities for observations. Exploring reality in a real context from the social actors' perspective will enable researchers to theorize and create new knowledge regarding the role of emerging innovative technologies to enhance the effectiveness of FSC risk mitigation strategies.

Although this study followed a quantitative research strategy, the research data were collected from six U.K.-based fashion companies; therefore, the findings are not fully transferable and can be generalized to only the participating case companies. Future research can focus on a larger sample of fashion companies by treating the U.K. fashion industry as the entire research population. Future research can also extend our knowledge by replicating this research in other industries, such as the fresh food, electric vehicles, and renewable energy industries. Similarly, future researchers can also replicate this research in non-U.K. markets to explore the risk factors, mitigation strategies, and the use of emerging innovative technologies.

Appendix

A. Key Search Strings Applied to Search Empirical Papers

1) "Fashion" AND "risk."
2) "Fashion" OR "risk."
3) "Supply chain" AND "risk."
4) "Fashion" AND "technology."
5) "Supply chain" AND "technology."
6) "Fashion" AND "risk" AND "fuzzy."
7) "Fashion" AND "digital" AND "risk."
8) "fashion" AND "risk" AND "mitigation."
9) "Supply chain" AND "digital" OR "technology."
10) "Technology" AND "risk" AND "supply chain."
11) "Fashion" AND "technology" AND "supply chain."
12) "Supply chain" AND "risk" OR "mitigation" AND "subfactor."
13) "Supply chain" AND "risk" OR "mitigation" AND "root causes."
14) "Supply chain" AND "Fuzzy" AND "decision making."
15) "Supply chain" AND "risk" AND "technology" OR "innovative" OR "modern."
16) "Supply chain" AND "risk" AND "fashion" AND "technology" AND "emerging."

B. Results for the RPN Sensitivity Analysis by Changing of Risk Factors' Weights

	Avoid, Transfer and Share	Sourcing Strategy (Multiple, Local)	Buffers and Safety Stock	Planning and Decision Making	Workforce and Management Development	Communication and Information Sharing	Building Relationships	Designing a Resilient System/SC	Supply Chain Redesign for Flexibility, Agility, and Responsiveness	Using Technology	Audits, Inspection, and Monitoring	Creating a Risk Management Culture	Insurance and Hedging	Resource Sharing
Current weights	322.6	306.0	270.7	238.9	231.1	185.3	155.6	146.2	150.6	207.0	209.9	**128.8**	199.7	141.4
Social weight *2	315.7	301.6	268.1	235.0	229.3	182.3	153.7	144.2	151.2	205.3	208.3	**126.7**	199.4	141.1
Social weight *3	308.8	297.3	265.5	231.1	227.5	179.2	151.9	142.3	151.8	203.6	206.7	**124.7**	199.1	140.8
Social weight *4	301.8	293.0	263.0	227.2	225.7	176.1	150.1	140.3	152.3	201.9	205.0	**122.6**	198.7	140.4
Environmental weight *2	321.8	306.0	270.8	237.1	232.1	184.6	155.0	146.4	150.7	206.2	208.4	**128.8**	198.3	140.8
Environmental weight *3	321.1	306.0	271.0	235.3	233.1	183.9	154.4	146.5	150.8	205.4	206.9	**128.9**	196.9	140.2
Environmental weight *4	320.3	306.1	271.1	233.6	234.1	183.1	153.8	146.6	150.9	204.6	205.4	**128.9**	195.5	139.6
Economical weight *2	347.1	299.3	269.1	235.3	204.1	168.1	152.5	142.5	138.8	191.1	185.5	**124.6**	180.5	141.5
Economical weight*3	371.7	292.6	267.4	231.8	177.0	150.9	149.4	138.8	127.1	175.1	161.1	**120.3**	161.3	141.5
Economical weight*4	383.9	289.2	266.5	230.0	163.4	142.3	147.8	137.0	121.2	167.1	148.9	**118.2**	151.7	141.6
Operational weight*2	338.1	323.0	286.2	255.9	247.5	196.3	171.4	163.8	163.5	224.9	226.0	**129.6**	215.2	146.8
Operational weight*3	353.6	340.0	301.8	272.8	263.8	207.2	187.2	181.4	176.5	242.8	242.0	**130.4**	230.7	152.2
Operational weight*4	369.1	357.0	317.3	289.8	280.1	218.2	203.0	199.0	189.4	260.7	258.0	**131.2**	246.1	157.5
Reputational weight*2	302.8	316.3	267.4	233.5	243.6	194.1	150.6	**135.9**	149.5	202.5	213.9	139.7	198.5	139.9
Reputational weight*3	282.9	326.7	264.1	228.1	256.0	202.8	145.5	**125.6**	148.3	197.9	217.9	150.5	197.3	138.4
Reputational weight*4	278.0	329.3	263.2	226.8	259.1	205.0	144.3	**123.0**	148.1	196.8	218.9	153.2	197.0	138.1
Market weight*2	323.0	306.6	270.4	238.6	231.9	184.9	155.8	145.9	150.1	206.3	211.5	**128.4**	200.2	140.8
Market weight*3	323.5	307.2	270.0	238.4	232.6	184.5	156.1	145.6	149.5	205.6	213.1	**128.0**	200.7	140.2
Market weight*4	323.9	307.7	269.6	238.1	233.3	184.0	156.3	145.3	149.0	204.9	214.7	**127.5**	201.2	139.6
Product weight*2	320.1	303.1	269.6	237.3	229.7	183.6	154.4	145.2	149.2	205.7	210.1	**128.3**	198.8	140.7
Product weight*3	317.6	300.3	268.5	235.6	228.2	181.9	153.3	144.1	147.7	204.4	210.2	**127.9**	197.8	139.9
Product weight*4	315.1	297.5	267.4	234.0	226.7	180.1	152.2	143.1	146.3	203.0	210.4	**127.5**	196.9	139.1
Disruption weight*2	310.6	292.6	264.1	236.3	227.8	187.8	149.9	144.6	149.9	212.0	213.8	**125.3**	203.5	141.4
Disruption weight*3	298.6	279.2	257.5	233.7	224.5	190.2	144.2	142.9	149.2	217.0	217.7	**121.8**	207.3	141.3
Disruption weight*4	286.6	265.8	250.9	231.1	221.1	192.6	138.4	141.2	148.4	221.9	221.5	**118.4**	211.0	141.2
Complexity weight*2	322.2	304.5	271.2	238.7	231.1	184.4	154.9	145.4	150.1	207.1	209.3	**127.9**	199.5	140.5
Complexity weight*3	321.8	303.1	271.7	238.5	231.1	183.4	154.1	144.6	149.5	207.2	208.7	**127.0**	199.4	139.6
Complexity weight*4	321.4	301.7	272.1	238.4	231.0	182.4	153.4	143.8	149.0	207.2	208.1	**126.1**	199.2	138.7
Workforce weight*2	325.8	308.9	270.2	240.3	232.8	186.9	156.7	146.3	151.1	206.1	209.5	**130.5**	200.0	141.1
Workforce weight*3	329.1	311.9	269.6	241.7	234.4	188.4	157.9	146.3	151.6	205.2	209.2	**132.1**	200.2	140.7
Workforce weight*4	332.3	314.8	269.1	243.2	236.0	190.0	159.1	146.4	152.2	204.2	208.8	**133.8**	200.5	140.3
Variance	567	289	142	163	461	203	147	189	132	266	359	**56**	258	**15**

The bold entities indicate the best performance.

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