Journal of Information Technology Management
ISSN-OnLine: 2980-7972
University of Tehran

Risk-Driven Capability Development in Global Supply Chain Resilience: Implications for Digitalization

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Journal of Information Technology Management, 2026, Vol. 18, Issue 3, pp. 82-107
Published by the University of Tehran, College of Management
doi: https://doi.org/10.22059/jitm.2026.414800.4475
Article Type: Research Paper

Received: January 24, 2026
Received in revised form: March 19, 2026
Accepted: May 14, 2026
Published online: July 01, 2026

Abstract

This study examines supply chain risk management and resilience capabilities in the automotive parts manufacturing sector, with particular attention to the role of digitalization in mitigating high-priority risks. Using a four-phase methodology, the research first identifies 35 supply chain risks from the literature, categorizing them into supply, operational, demand, and environmental risks. In the second phase, a survey of 164 managers from 47 firms refines these risks into 18 key factors using Exploratory Factor Analysis (EFA) and Confirmatory Factor Analysis (CFA). The third phase employs the Fuzzy Analytic Hierarchy Process (Fuzzy AHP), integrating pairwise comparisons from 21 CEOs to assess the probability and impact of each risk, classifying them into three action groups: immediate action, observation, and no action. Seven risks fall into the immediate action group: quality risk, supplier capacity disruption, sourcing flexibility risk, resource risk, market risk and competition, geopolitical risk, and macroeconomic and technological risk. In the final phase, each immediate action risk is mapped to specific firm capabilities, with emphasis on how digital technologies, including supply chain visibility platforms, data analytics, and digital procurement tools, can strengthen these capabilities and sustain firms within the zone of balanced resilience. The findings provide actionable guidance for managers on aligning digitalization investments with the most critical risk exposures, avoiding capability gaps and profit erosion. The study concludes by proposing a risk-driven capability development framework with implications for digital transformation in global supply chains.

Keywords: Supply Chain Risk Management (SCRM), Global Value Chains (GVC), Risk Assessment, Automotive Industry, Global Supply Chain

Introduction

Global supply chains in the automotive industry have evolved into intricate, geographically dispersed networks, enhancing efficiency but also increasing vulnerability to disruptions (Tang & Musa, 2011). Automotive manufacturers often employ lean, just-in-time (JIT) production systems to minimize inventory and optimize costs (Chopra & Sodhi, 2014; García-Cutrín et al., 2024). However, these tightly coupled systems can make firms susceptible to cascading failures; disturbances such as supplier shutdowns or logistics bottlenecks in one region can rapidly propagate across the entire supply network (Ivanov & Dolgui, 2020). Empirical studies indicate that a significant majority of firms experience at least one major supply chain disruption annually, underscoring the persistent nature of these challenges (Hamidu, 2023; Jüttner & Maklan, 2011). The automotive sector has been particularly affected by such shocks. For instance, the 2011 Tōhoku earthquake and tsunami in Japan severely impacted key suppliers, leading to substantial production losses for manufacturers like Toyota (MacKenzie et al., 2012). More recently, the COVID-19 pandemic exacerbated vulnerabilities, causing severe supply shortages, particularly in semiconductor chips, which disrupted global auto production (Shih, 2020). Additionally, ongoing trade disputes, such as the China-US trade war, have highlighted the inherent risks in global supply chains (Cai & Li, 2022). In this context, digitalization has emerged as a critical enabler of supply chain resilience, offering firms tools for real-time visibility, risk monitoring, and adaptive capability development (Ivanov & Dolgui, 2020). These events underscore that disruptions are inevitable, reinforcing the need for resilience strategies in global supply chain participation.

Supply chain resilience is defined as "the ability of a supply chain to anticipate, respond to, and recover from disruptions while maintaining operational continuity" (Pettit et al., 2013). Research indicates that a structured approach to supply chain risk management (SCRM) can significantly enhance resilience (Ben-Daya et al., 2019; Scholten et al., 2014). Tools and frameworks developed for assessing supply chain vulnerabilities have been shown to provide valuable insights into the interconnections between risks and capabilities (Pettit et al., 2013). However, it is important to note that while enhancing resilience is crucial, excessive investments in resilience without proper alignment to actual risk exposure can lead to resource wastage or profit erosion (Marino & Lange, 1983; Pettit et al., 2013; Klibi, 2024). Therefore, a balanced approach is necessary to ensure that resilience efforts are both effective and efficient (Lyons, 2014; Pettit et al., 2010). Saffarinia et al., (2026) proposed a framework can serve as a robust decision-support tool for managers and policymakers to design supply chain networks that are resilient, cost-efficient, and environmentally sustainable. Ghadami et al., (2026) clarifies a conceptual contours, highlights collaboration hubs led by the United States, India, and China, and delineates gaps that motivate future work on data governance, technical integration, and evaluation across sectors. Also Ebrahimi Kordlar and Zakeri (2009) investigated earnings management through the sale of firm assets. One of the factors that previous studies have identified as an influential factor in Earning Response Coefficient (ERC) is default risk (Ebrahimi Kordlar & Mohammadi Shad, 2014). Ebrahimi Kordlar and Aarabi (2010) review the relationship between ownership concentration and earnings quality by testing the data collected from 148 listed companies in the Tehran's Stocks Exchange.

Despite increased attention to resilience, several research gaps remain. Firstly, while numerous studies have explored supply chain risks in general (Manuj & Mentzer, 2008; Tang & Musa, 2011), there is limited research specifically addressing the unique risk landscape faced by manufacturing firms participating in global supply chains. Secondly, most studies either focus on risk identification or propose resilience frameworks without systematically linking specific risks to resilience capabilities (Giannakis & Papadopoulos, 2016). Thirdly, much of the existing research is conceptual, lacking empirical validation of how resilience behaves during participation in global supply chains under real-world disruptions (Scholten & Schilder, 2015).

Furthermore, the role of digitalization in translating risk prioritization into targeted capability development remains underexplored, representing a gap this study seeks to address. Thus, the key objectives of this study are to: (1) identify significant risks faced by manufacturing firms participating in supply chains, particularly in the automotive sector; (2) assess risk categories based on the impact and probability of each risk to classify them into different action levels; and (3) determine the capabilities associated with each immediate action risk category and examine how digitalization can strengthen these capabilities to optimize resource allocation and enhance firm resilience in global supply chains.

Literature Review

This study builds upon the foundational concepts of supply chain risk management (SCRM) by systematically integrating risk identification, risk assessment, risk-linked capabilities, resilience analysis, and strategic responses to resilience in global supply chains. Effective risk management remains a critical challenge, as many firms still lack robust mechanisms to systematically identify, assess, and mitigate risks within their supply networks. Despite widespread awareness of supply chain risks, only a minority of firms implement proactive and structured risk management strategies. A key challenge in SCRM lies in managing the diverse and interconnected risks across different tiers of the supply chain. Identifying the relevance and impact of each specific risk is crucial, as risks vary significantly in their potential to disrupt supply chain operations. Following the initial risk identification phase, Wittmann (2000) introduced the probability-impact framework, which assesses risks based on their likelihood of occurrence and their disruptive potential across the supply chain. The risk category matrix is defined based on Wittmann's (2000) scale dimensions of probability and impact, and its implementation by Thun and Hoenig (2011) establishes three distinct risk categories. The hatched area represents Risk A (Low Risk-Minor), where risk is considered acceptable, and actions are not required but remain possible. This category represents the lowest level of vulnerability and can be managed within routine organizational operations. The white area denotes Risk B (Medium Risk), where risk shall be reduced, and actions are required. These risks need planning and attention within standard management processes and should be addressed in routine organizational operations management planning. The black area indicates Risk C (High Risk), where risk is deemed unacceptable and immediate actions are required. This category represents the greatest vulnerability and requires planning and responses outside the scope of routine operations, falling within the realm of crisis management actions. In this matrix, the x-axis represents the probability of risk occurrence, and the y-axis represents risk impact (Figure 1).

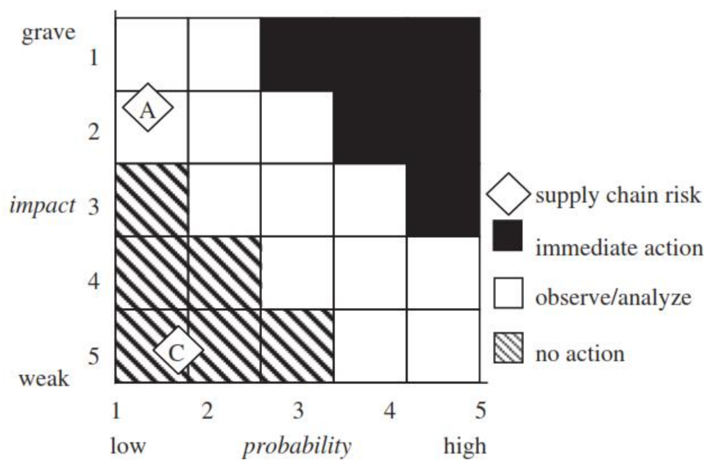

Figure 1. Probability-impact-matrix

In this framework, risks with high probability and high impact (Risk C) represent the greatest vulnerability, indicating hazards that haven't received sufficient management attention despite their critical nature. Conversely, risks with low probability and minimal effects (Risk A) demonstrate the lowest level of vulnerability and require less intensive planning. Medium risks (Risk B) require balanced attention and systematic management approaches to ensure appropriate risk reduction measures are implemented (Sheffi, & Rice, 2005).

Accurately quantifying these risk levels remains a challenge, as precise estimations of probability and impact are difficult to establish. To address this limitation, Laarhoven and Pedrycz (1983) introduced the Fuzzy Analytic Hierarchy Process (FAHP), which integrates Analytic Hierarchy Process (AHP) with Fuzzy Theory to enhance decision-making under uncertainty. FAHP enables decision-makers to express subjective risk assessments using fuzzy numbers and membership functions, improving the accuracy of risk prioritization. Furthermore, this study applies the Similarity Aggregation Method (SAM) (Hsu & Chen, 1996) to integrate expert judgments, ensuring a comprehensive and structured evaluation of risk factors.

Risk assessment and categorization alone do not ensure supply chain stability; organizations must also develop resilience capabilities to counterbalance vulnerabilities. The Supply Chain Resilience Framework (SCRF) proposed by Pettit et al. (2011) provides a structured approach to understanding resilience by emphasizing two fundamental components: vulnerabilities, which are factors that make a supply chain susceptible to disruptions, and capabilities, which are attributes that enable firms to anticipate, absorb, and recover from disruptions. Pettit et al. (2013) further propose that resilience is optimized when there is a balance between vulnerabilities and capabilities, forming what is termed the Zone of Balanced Resilience. A firm that lacks adequate capabilities relative to its vulnerabilities remains highly exposed to risks, whereas excessive investment in resilience measures can erode profitability. Achieving resilience, therefore, requires firms to develop capabilities that are proportionate to their vulnerabilities.

Effective risk mitigation involves selecting appropriate resilience strategies tailored to different risk environments. Um and Han (2021) identify seven key resilience strategies that firms can adopt: acceptance, which involves acknowledging certain risks as unavoidable and adapting business models accordingly; avoidance, which eliminates sources of risk through strategic decisions such as supplier diversification; postponement, which delays commitments in supply chain operations to retain flexibility; speculation, which involves making proactive investments to secure market advantages; hedging, which uses financial and operational strategies to offset risks; sharing or transfer, which distributes risks across supply chain partners; and control, which directly manages risks through robust operational processes. The effectiveness of these strategies depends on the nature of the risks faced. While more intensive risk mitigation enhances resilience, over-reliance on a single strategy may not always yield optimal results. A dynamic and context-dependent approach is required to ensure resilience while maintaining operational efficiency and profitability.

Literature Review

Risk identification and analysis is one of the crucial stages in the risk management process (Shahsavari et al., 2024). Through risk identification, decision-makers become aware of events that could potentially disrupt company operations. For evaluating supply chain risks, not only must the risks that directly impact company operations be identified, but also the potential causes or sources of these risks at different levels of the supply chain must be recognized (Norrman & Jansson, 2004). Many classifications have been presented for supply chain risks, each considering different factors and drivers as their basis for classification. Mason-Jones and Towill (1998) identified five categories of supply chain risks: environmental, supply, demand, process, and control risks. Chopra and Sodhi (2004) classified supply chain risks into eight categories (disruptions, delays, systems, forecasting, intellectual property, procurement, receivables, inventory, and capacity) and presented general strategies for each category. Tomlin (2006) also classified these risks into three categories: supply risk, process risk, and demand risk (Tomlin, 2006). Through a comprehensive review of supply chain risk literature, we categorized these risks into four groups: supply risk, operational risk, demand risk, and environmental risk, and then identified the drivers for each risk category (Table 1). We will explain each of these four categories below.

Supply Risks: Kraljic (1983) was among the first to emphasize that companies must evaluate and manage uncertainty in supplier relationships to protect themselves against costly supply disruptions (Wagner & Bode, 2008). The need to assess and manage supply-side risks has intensified with increased reliance on external sources for critical materials and components (Giunipero & Eltantawy, 2004). Supply risks relate to events that affect the integrity of supplier operations and result in suspension or termination of supplier-buyer relationships (Wagner & Bode, 2008).

Operational Risks: Operational risks are those that affect a company's internal ability to produce goods and services (Cucchiella & Gastaldi, 2006). Moreover, the concept of operational risk not only concerns risks threatening the production process but also encompasses information flowing through an organization's information network and between organizations (Chopra & Sodhi, 2004).

Demand Risks: Demand-side risks arise from uncertainty associated with unpredictable customer demand. In other words, these risks are created due to mismatches between forecasted and actual demand quantities (Wagner & Bode, 2008). Generally, demand risks relate to disruptions in the flow of products, information, and cash between supply chain components and the market (Christopher & Lee, 2004).

Environmental Risks: Environmental risks arise from supply chain interactions with the environment (Juttner et al., 2003). These environments include physical, social, political, legal, operational, and economic environments (Bogataj & Bogataj, 2008). Environmental events can directly impact key supply chain elements or jeopardize supply chain performance through their effects on the market. They may also affect a specific value stream or any node or connection along the supply chain. These risks might result from social, political, or technological events occurring at great physical distances from supply chain elements yet having significant impacts on the supply chain (Christopher & Lee, 2004).

Table 1. Supply Chain Risk Classification based on literature

Initial Classification	Risk factor	Abbreviation	Author
Supply Risk	Delay Risk	SR 1	Liu et al. (2009); Bogataj & Bogataj (2007)
	Quality Risk (e.g. Material)	SR 2	Liu et al. (2009); Manuj and Mentzer (2008a, 2008b); Matook et al. (2008); Wagner & Bode (2008); Sreedevi and Saranga (2017)
	Coordination and Communication Risk	SR 3	Liu et al. (2009); Christopher & Peck (2004); Norrman & Jansson (2004)
	Supplier Financial Crisis and Bankruptcy Risk	SR 4	Liu et al. (2009); Chopra & Sodhi (2004); Manuj & Mentzer (2008a, 2008b); Kleindorfer & Saad (2005)
	Disruption in Information Exchange with Supplier	SR 5	Christopher & Peck (2004)
	Supply capacity disruption (e.g. single sourcing/material fulfilment)	SR 6	Chopra & Sodhi (2004); Manuj & Mentzer (2008a, 2008b), Olson & Wu (2010), Tang & Musa (2011), Tummala & Schoenherr (2011); Sreedevi & Saranga (2017)
	Supplier relationships (e.g. Contract Breach)	SR 7	Chopra & Sodhi (2004); Bak (2017)
	Sourcing flexibility risk (e.g. scheduling and transit time)	SR 8	Chopra & Sodhi (2004); Manuj & Mentzer (2008a, 2008b); Tang & Musa (2011); Tummala & Schoenherr (2011)
Operational Risk	Production Capacity disruption	OR 1	Liu et al. (2009); Chopra & Sodhi (2004); Manuj & Mentzer (2008a, 2008b); Wagner & Bode (2008); Sreedevi & Saranga (2017); Olson & Wu (2010), Tummala & Schoenherr (2011), Tang & Musa (2011)
	Production Units Integration and Coordination Risk	OR 2	Liu et al. (2009); Tang, (2006)
	Investment risk	OR 3	Chopra & Sodhi (2004); Chereau & Schellhorn (2014)
	Product Quality	OR 4	Bogataj & Bogataj (2007); Manuj & Mentzer (2008a, 2008b), Olson & Wu (2010), Tummala & Schoenherr (2011); Tan et al. (2014)
	Inventory disruption (e.g. excess inventory/obsolescence)	OR 5	Chopra & Sodhi (2004); Matook et al. (2008); Manuj & Mentzer (2008a, 2008b); Tang & Musa (2011); Tummala & Schoenherr (2011); Sreedevi & Saranga (2017)
	Production Delay	OR 6	Bogataj & Bogataj (2007); Kusrini et al (2020); Elangovan et al (2010); Chopra & Sodhi (2004)
	Employee efficiency risk	OR 7	Norrman & Jansson (2004); Jiang et al., (2009); Narasimhan & Talluri (2009)
	Product/process design	OR 8	Matook et al. (2008); Manuj and Mentzer (2008a, 2008b); Wagner & Bode (2008); Sheffi, & Rice (2005); Rice (usa (2011)
	Information Systems	OR 9	Chopra & Sodhi (2004); Norrman & Jansson

	Security and Disruption		(2004); Manuj and Mentzer (2008a, 2008b); Sheffi & Rice (2005)
	Resource Risk	OR 10	Manuj & Mentzer (2008); Bell et al., (2012); Tang & Musa (2011); Bell et al., (2013)
	Transportation and logistics reliability (e.g. order fulfilment error/delay)	OR 11	Oke & Gopalakrishnan (2009); Wagner & Bode (2008); Sheffi, & Rice (2005); Olson & Wu (2010); Tang & Musa (2011); Tummala & Schoenherr (2011); Sreedevi & Saranga (2017)
	Logistic cost (e.g. transportation and inventory)	OR 12	Meixell and Gargeya (2005); Peng et al (2014); Arvis et al (2007); Manuj et al., 2014
	Service quality (Quality Maintenance)	OR 13	Wagner & Bode (2008); Tummala & Schoenherr (2011); Hallikas et al. (2004)
Demand Risk	Sales Contract Breach	DR 1	Liu et al. (2009); Bak (2017); Finch (2004); Chopra & Sodhi (2004); Cafaggi & Iamiceli (2015)
	Market risk (e.g. Loss of Market Share, MNC and incumbent company Competition)	DR 2	Hallikas et al. (2004); Giannakis & Papadopoulos (2016); Manuj & Mentzer (2008a, 2008b), Olson & Wu (2010), Christopher, & Lee, (2004); Cao et al., (2015); Xu & Xiao (2023); Birkinshaw (2023); Bergek et al (2013)
	Unpredictable Demand	DR 3	Liu et al. (2009); Oke & Gopalakrishnan (2009); Bogataj & Bogataj (2007); Chopra & Sodhi (2004
	New Product Introduction	DR 4	Manuj & Mentzer (2008a, 2008b); Bak (2017); Schoenherr & Swink (2015); Petersen et al (2005)
	Short Product Life Cycle	DR 5	Oke & Gopalakrishnan (2009); Chopra & Sodhi (2004); Hallikas et al. (2004)
	Demand variation	DR 6	Oke & Gopalakrishnan (2009); Chopra & Sodhi (2004); Olson & Wu (2010); Tang & Musa (2011); Tummala & Schoenherr (2011)
	Incomplete Customer Information	DR 7	Wagner & Bode (2008)
	Price Risk	DR 8	Chopra & Sodhi (2004); Fischl et al., (2014); Tang, (2006); Mitra & Sarkar (2022)
Environmental Risk	Sociocultural Risk (e.g. Cultural differences, Social responsibility issues)	ER 1	Oke & Gopalakrishnan (2009); Chopra & Sodhi (2004); Christopher & Lee (2004); Norrman & Jansson (2004); Matook et al. (2008); Wagner & Bode (2008); Chukwuka et al., (2023)
	Regulatory/ Intergovernmental administration Risk (e.g. Compliance requirements)	ER 2	Liu et al. (2009); Chopra & Sodhi (2004); Wagner & Bode (2008); Darnall et al., (2019); Zhu et al., (2017)
	Geopolitical risks (e.g. regional tensions, War)	ER 3	Christopher & Peck (2004); Wagner & Bode (2008); Kleindorfer & Saad (2005); Caldara & Iacoviello (2022); Cheng & Chiu, (2018)
	Natural and disease Disasters (e.g. Earthquake, Climate Change)	ER 4	Oke & Gopalakrishnan (2009); Christopher & Peck (2004); Chopra & Sodhi (2004); Matook et al. (2008); Wagner & Bode (2008); Kleindorfer & Saad (2005); Sheffi, & Rice (2005)
	Unforeseen technology failures	ER 5	Wagner & Bode (2008); Sheffi, & Rice (2005); Rice (usa (2011)
	Macroeconomic risk (e.g. Exchange rate fluctuations, financial crises, sanctions, new tariff)	ER 6	Kleindorfer & Saad (2005); Oke & Gopalakrishnan (2009); Manuj & Mentzer (2008); Matook et al. (2008); Sheffi, & Rice (2005); Pellegrino et al (2024); Badhan et al. (2024); Anguzu & Aila (2024); Ke et al (2018).

Methodology

This study employs a mixed-methods approach and conducted in multiple phases, beginning with a comprehensive literature review that led to the identification of 35 distinct supply chain risk factors, as outlined in Table 1. In the first phase with using explaratory factor analysis (EFA) and Confirmatory Factor Analysis (CFA) method to empirically validate the underlying structure of risk factors and reduce dimensionality and To confirm the factor structure identified through EFA and assess the model fit. for this a structured two-part questionnaire was designed. The first part gathered demographic and company data from respondents, with a summary of the results provided in Tables 2 and 3. The second part comprised a 5-point Likert scale (1 = very low, 5 = very high) measuring the significance of the 35 identified risk factors. The questionnaire was distributed to 178 respondents across 47 automotive parts manufacturing companies, yielding 164 valid responses, corresponding to a response rate of 92.1%.

Table 2. Respondent Information

Experience			Position		
Years of Experience	Frequency	Percentage	Role	Frequency	Percentage
< 5 years	27	16.5%	CEO	21	12.8%
5-10 years	80	48.8%	Senior Manager	93	56.7%
> 10 years	57	34.7%	Expert/Specialist	50	30.5%

Table 3. Company Information

Company Operation History			Number of Employees			Annual Sales		
Years in Operation	Frequency	Percentage	Employee Count	Frequency	Percentage	Sales Volume	Frequency	Percentage
< 5 years	4	8.5%	< 100	5	10.6%	< 1 Billion	8	17.0%
5-10 years	18	38.2%	100-500	26	55.3%	1-10 Billion	21	44.7%
> 10 years	25	53.3%	> 500	16	34.1%	> 10 Billion	18	38.3%

In the second phase, to determine the action category for each risk, we assess the probability and impact of 18 main risks using the Fuzzy Analytic Hierarchy Process (FAHP) method. To achieve this, we designed a second questionnaire consisting of 38 pairwise comparisons, using the scale presented in Table 2 and Figure 3. The pairwise comparisons include six comparisons within the main risk factors, ten comparisons within the five supply risk factors, ten comparisons within the five operational risk factors, six comparisons within the four demand risk factors, and six comparisons within the four environmental risk factors. The second questionnaire matrix is structured using a 1-to-5 scale (e.g., where 1 = equally important and 5 = extremely important) and was administered to the 21 CEOs who participated in the first phase.

In the third phase, we identify relevant capabilities for each risk based on the capability framework proposed by Petit et al. (2013). This process relies on secondary data sources, including grey literature on the Iranian automotive industry, global reports on the automotive sector, memos, and governmental documents.

Results

Exploratory factor analysis (EFA)

To assess the suitability of the dataset for factor analysis, the Kaiser-Meyer-Olkin (KMO) test and Bartlett's test of sphericity were conducted, following Hair et al. (2010). The KMO index yielded a value of 0.773, indicating adequate sampling adequacy, while Bartlett's test produced a statistically significant result ($\chi^2 = 4307.56$, $p < 0.001$), confirming the presence of sufficient correlations among variables for factor extraction. As per Kaiser (1974), KMO values above 0.70 indicate that the sample size is sufficient for reliable factor analysis. The number of factors was determined using the eigenvalue criterion and percentage of explained variance, following the guidelines of Tabachnick and Fidell (2013). Factors with eigenvalues greater than 1.0 were retained, ensuring that the extracted factors collectively explained at least 60% of the total variance, a threshold recommended by Hair et al. (2010). The final extracted factors accounted for 69.3% of the total variance, surpassing the required minimum and reinforcing the robustness of the factor structure.

The results of the Cronbach's α reliability test, KMO test, and variance explained by each factor are presented in Table 3. Cronbach's α values for all factors exceeded 0.88, indicating strong internal consistency. The KMO values for individual factors ranged from 0.855 to 0.881, confirming sampling adequacy for factor analysis. The total variance explained by each factor further validates the extracted factor structure.

Table 4. Cronbach's α, Kaiser-Meyer-Olkin (KMO), and Variance Explained by Factors

Factors	Risk Category	Cronbach's α	Total Variance Explained (%)	KMO Test Value	Single-Factor Variance Explained (%)
1	Supply Risk	0.91	20.787	0.881	73.009
2	Operational Risk	0.91	18.444	0.863	59.021
3	Demand Risk	0.90	18.968	0.855	70.641
4	Environmental Risk	0.88	17.994	0.872	63.212

The table confirms that all factors exhibit high reliability (Cronbach's $\alpha > 0.88$), strong KMO values (> 0.85), and significant variance explained. These findings validate the robustness of the extracted factor structure and support its suitability for further analyses.

Factor extraction was performed using Principal Axis Factoring (PAF), and Varimax rotation was applied to enhance interpretability. A factor loading threshold of 0.6 was set to retain only variables with substantial contributions to the identified factors, in line with the recommendations of Fornell and Larcker (1981). Variables with weak loadings were systematically removed to ensure model reliability and validity. The EFA results confirmed the presence of four main risk categories: supply risk, operational risk, demand risk, and environmental risk. Following factor analysis, a refinement process was conducted to improve conceptual clarity and statistical reliability. Within the supply risk category, SR.1 (Delay Risk) and SR.7 (Supplier Relationships - Contract Breach) were removed due to correlation coefficients below 0.6. Additionally, SR.3 (Coordination and Communication Risk) was merged with SR.5 (Disruption in Information Exchange), as coordination failures often lead to disruptions in information flow, making them conceptually interdependent. In the operational risk category, several factors exhibited weak correlations and were consequently removed, including OR.1 (Production Capacity Disruption), OR.2 (Production Units Integration and Coordination Risk), OR.3 (Investment Risk), OR.6 (Production Delay), OR.7 (Employee Efficiency Risk), and OR.13 (Service Quality). Furthermore, OR.4 (Product Quality) was merged with OR.8 (Product/Process Design), as product design deficiencies are a primary cause of quality failures, making them conceptually linked. For the demand risk category, DR.3 (Unpredictable Demand), DR.7 (Incomplete Customer Information), and DR.8 (Price Risk) were eliminated due to weak correlations. Additionally, DR.4 (New Product Introduction) was merged with DR.5 (Short Product Life Cycle), as frequent product introductions typically contribute to shorter life cycles, reinforcing their conceptual alignment.In the environmental risk category, ER.1 (Sociocultural Risk) was excluded, as its impact was already captured under ER.2 (Regulatory and Intergovernmental Risks). Similarly, ER.5 (Unforeseen Technology Failures) was merged with ER.6 (Macroeconomic Risk), given that technological disruptions often stem from broader macroeconomic conditions, financial crises, and regulatory shifts.

Confirmatory Factor Analysis (CFA)

Building upon the Exploratory Factor Analysis (EFA) results, Confirmatory Factor Analysis (CFA) was conducted to validate the measurement model and confirm the underlying factor structure. The adequacy of the measurement model was assessed using multiple fit indices, including Chi-square/degrees of freedom (χ^2/df), Comparative Fit Index (CFI), Tucker-Lewis Index (TLI), and Root Mean Square Error of Approximation (RMSEA). Following the recommendations of Byrne (2016) and Kline (2015), a well-fitting model should meet the following criteria: χ^2/df < 5, CFI and TLI > 0.90, and RMSEA < 0.08.As shown in Table 5, the CFA results indicate an acceptable model fit, confirming the structural validity of the identified risk categories.

Table 5. Confirmatory Factor Analysis Model Fit Indices

Model Fit Index	Recommended Threshold	CFA Results
χ^2/df	< 5	3.42
CFI	> 0.90	0.921
TLI	> 0.90	0.907
RMSEA	< 0.08	0.067

The model fit indices support the validity of the measurement model, confirming that the retained risk factors provide a reliable representation of the underlying constructs.

To assess construct validity, Nunnally's single-factor method (Nunnally & Bernstein, 1994) was applied separately to each dimension. This approach required that each construct be extracted as a single valid factor. The Kaiser-Meyer-Olkin (KMO) test was also performed on each single-factor extraction, with all KMO values falling within the acceptable range prescribed by Kaiser (1974), further confirming the adequacy of the sample for each construct.

Convergent validity was established by evaluating factor loadings, Average Variance Extracted (AVE), and Composite Reliability (CR). Factor loadings for all retained items exceeded 0.6, aligning with Fornell and Larcker's (1981) recommendations. AVE values were above 0.50, confirming that each latent construct captured a substantial proportion of variance relative to measurement error. Additionally, CR values exceeded 0.70, demonstrating strong internal consistency (Hair et al., 2010; Nunnally & Bernstein, 1994). Discriminant validity was assessed using two complementary approaches: 1) Fornell and Larcker's (1981) criterion, which states that the square root of AVE for a construct should be greater than its highest correlation with any other construct.2) Squared correlation comparison, where discriminant validity is confirmed if the AVE for each construct is greater than the squared correlation between constructs (Ghosh & Jintanapakanont, 2004). As presented in Table 5, both methods confirm that the four risk categories are statistically distinct.

Table 6. Convergent and Discriminant Validity

Risk Category	AVE	CR	Square Root of AVE	Max Inter-Factor Correlation
Supply Risk	0.57	0.89	0.75	0.49
Operational Risk	0.60	0.91	0.77	0.42
Demand Risk	0.56	0.90	0.75	0.46
Environmental Risk	0.59	0.88	0.77	0.50

Since the square root of AVE for each construct is greater than both its highest inter-factor correlation and highest squared correlation, discriminant validity is confirmed.

Additionally, Table 6 presents the inter-factor correlation matrix, reinforcing the distinction between constructs.

Table 7. Inter-Factor Correlation Matrix

	Supply Risk	Operational Risk	Demand Risk	Environmental Risk
Supply Risk	1.000			
Operational Risk	0.142	1.000		
Demand Risk	0.032	-0.005	1.000	
Environmental Risk	-0.056	-0.056	-0.083	1.000

The final set of validated risk factors—confirmed through rigorous statistical and conceptual refinement—establishes a robust foundation for further analysis of supply chain resilience in the automotive sector.

Table 8. Final main categories and subcategories resulted in EFA and CFA

Main category	Risk Factor	Final Risk factor name	Factor loading	Correlation Coefficient
Supply Risk	SR.2	Quality Risk	0.801	0.705
	SR.4	Supplier Financial Crisis	0.835	0.763
	SR.5	Information Exchange Disruption	0.887	0.876
	SR.6	Supplier Capacity Disruption	0.857	0.652
	SR.8	Sourcing Flexibility Risk	0.708	0.676
Operational Risk	OR.5	Inventory Disruption	0.730	0.616
	OR.8	Product Quality & Process Design	0.720	0.605
	OR.9	Information Systems Security	0.637	0.751
	OR.10	Resource Risk	0.806	0.643
	OR.11	Logistics Reliability	0.707	0.797
Demand Risk	DR.1	Sales Contract Breach	0.729	0.727
	DR.2	Market Risk & Competition	0.756	0.657
	DR.5	New Product Introduction & Short Life Cycle	0.827	0.848
	DR.6	Demand Variation	0.883	0.768
Environmental Risk	ER.2	Regulatory/Administrative Risk	0.687	0.679
	ER.3	Geopolitical Risk)	0.846	0.660
	ER.4	Natural Disasters & Climate	0.856	0.719
	ER.6	Macroeconomic & Technological Risk	0.790	0.604

Fuzzy Analytic Hierarchy Process (FAHP)

Building upon the final selection of risk factors and subfactors identified in EFA and validated through CFA, a hierarchical decision model was developed, as illustrated in Figure 2.

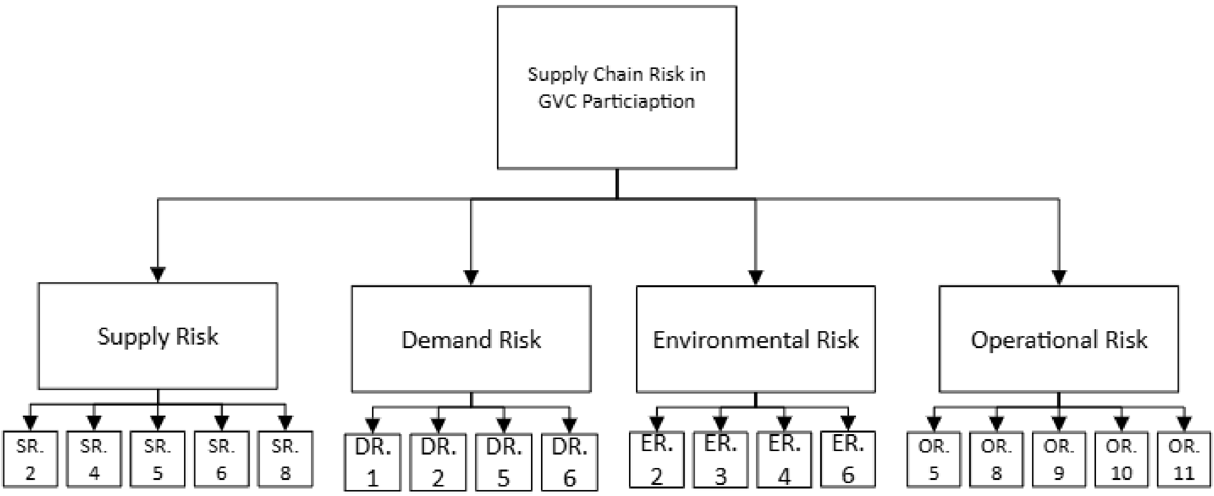

Figure 2. hierarchical decision model

Using this hierarchical structure, fuzzy paired comparison matrices were constructed, where decision-makers evaluated the relative importance of impact and probability for each factor through pairwise comparisons. These qualitative assessments were then converted into fuzzy numbers based on predefined linguistic scales, as presented in Table 9 and Figure 3.

Table 9. The definition of every fuzzy number

Fuzzy Number	Definition
= (1,1,1)$\tilde{1}$	Equally important
= (1,1.5,2)$\tilde{2}$	Judgment values between equally and moderately
= (2,2.5,3)$\tilde{3}$	Moderately more important
= (3,3.5,4)$\tilde{4}$	Strongly more important
= (4,4.5,5)$\tilde{5}$	Extremely more important

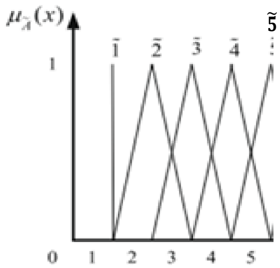

Figure 3. Scale of fuzzy numbers

To determine fuzzy weight values, the Column Vector Geometric Mean Method, proposed by Buckley (Ayhan, 2015), was employed. The fuzzy geometric mean for each row in the fuzzy pairwise comparison matrix was computed using the following formula:

$$Z_i = (a_{i1} \otimes a_{i2} \otimes \cdots \otimes a_{in})^{1/n} \quad \forall i \tag{1}$$

Where:

- a_{ij} represents the fuzzy comparison value between criterion i and j
- Z_i is the fuzzy geometric mean for each criterion.

Normalize the fuzzy weights using the fuzzy division method:

$$W_i = Z_i \oslash (Z_1 \oplus Z_2 \oplus \cdots \oplus Z_n) \tag{2}$$

Where:

- $\oplus$ denotes fuzzy addition of all Z_i values.
- $\oslash$ represents fuzzy division to normalize weights.

Connect all hierarchical levels in series to obtain the final weights of factors and sub-factors. Convert fuzzy weights into crisp values using the Center of Gravity (COG) method:

$$G(A) = \frac{\sum_{i=1}^{n} u_A(x_i) * x_i}{\sum_{i=1}^{n} u_A(x_i)} \tag{3}$$

Where:

- $G(A)$ represents the defuzzified value.
- $u_A(x_i)$ is the membership function of the fuzzy number at x_i

Finally, the defuzzified value were ranked in descending order to establish the relative importance of each risk factor and subfactor. For finding the global rank, The final weight of each sub-criterion was computed by multiplying the sub-criterion's weight by the weight of its parent category. A ranking was assigned based on the final weight, determining the global rank. If:

- W_i^{main} is the weight of the main category,
- W_{ij}^{sub} is the weight of the sub-criterion under that main category, Then the global weight of each sub-criterion is:

$$W_i^{global} = W_i^{main} * W_{ij}^{sub} \tag{4}$$

This method facilitates the calculation of characteristic vector values within a fuzzy decision matrix, enabling a structured determination of the final weight values assigned to each risk category and its subcomponents. The final weights of the main risk categories and their corresponding sub-criteria were obtained through FAHP, with the averaged pairwise comparison values presented in Table 4.

Table 9. Evaluation criteria weight of experts from different fields.

Main category	Risk Factor	Fuzzy Probability	Defuzzified Probability	Fuzzy Impact	Defuzzified Impact	Risk Value	Rank	Global rank
Supply Risk		(2.9996, 3.1996, 3.3996)	3.1996	(2.5942, 2.7942, 2.9942)	2.7942	9.3118	3	
	SR.2	(3.8853, 4.0853, 4.2853)	4.0853	(2.9168, 3.1168, 3.3168)	3.1168	12.7597	1	4
	SR.4	(3.6048, 3.8048,	3.8048	(2.6975, 2.8975,	2.8975	11.0511	4	7

		4.0048)		3.0975)				
	SR.5	(3.8182, 4.0182, 4.2182)	4.0182	(2.4951, 2.6951, 2.8951)	2.6951	10.8561	5	8
	SR.6	(3.6963, 3.8963, 4.0963)	3.8963	(2.9463, 3.1463, 3.3463)	3.1463	12.2856	3	6
	SR.8	(3.7878, 3.9878, 4.1878)	3.9878	(2.9341, 3.1341, 3.3341)	3.1341	12.5248	2	5
Operational Risk		(3.7177, 3.9177, 4.1177)	3.9177	(2.4011, 2.6011, 2.8011)	2.6011	10.3963	2	
	OR.5	(3.7854, 3.9854, 4.1854)	3.9854	(2.0134, 2.2134, 2.4134)	2.2134	8.8479	4	12
	OR.8	(3.4158, 3.6158, 3.8158)	3.6158	(2.2695, 2.4695, 2.6695)	2.4695	8.9559	3	11
	OR.9	(3.5865, 3.7865, 3.9865)	3.7865	(1.6109, 1.8109, 2.0109)	1.8109	6.8837	5	14
	OR.10	(4.2451, 4.4451, 4.6451)	4.4451	(3.8365, 4.0365, 4.2365)	4.0365	17.9693	1	1
	OR.11	(3.556, 3.756, 3.956)	3.756	(2.2756, 2.4756, 2.6756)	2.4756	9.325	2	9
Demand Risk		(3.2907, 3.4907, 3.6907)	3.4907	(2.1764, 2.3764, 2.5764)	2.3764	8.4084	4	
	DR.1	(3.3609, 3.5609, 3.7609)	3.5609	(2.0134, 2.2134, 2.4134)	2.2134	7.9084	3	16
	DR.2	(3.8304, 4.0304, 4.2304)	4.0304	(2.617, 2.817, 3.017)	2.817	11.3803	1	10
	DR.5	(2.9036, 3.1036, 3.3036)	3.1036	(1.8365, 2.0365, 2.2365)	2.0365	6.3472	4	17
	DR.6	(3.0682, 3.2682, 3.4682)	3.2682	(2.239, 2.439, 2.639)	2.439	7.9978	2	15
Environmental Risk		(3.7584, 3.9584, 4.1584)	3.9584	(2.7979, 2.9979, 3.1979)	2.9979	11.89546957	1	
	ER.2	(2.1963, 2.3963, 2.5963)	2.3963	(1.4219, 1.6219, 1.8219)	1.6219	3.9132	4	18
	ER.3	(3.3243, 3.5243, 3.7243)	3.5243	(3.6536, 3.8536, 4.0536)	3.8536	13.6079	1	2
	ER.4	(3.2024, 3.4024, 3.6024)	3.4024	(1.7638, 1.9638, 2.1638)	1.9638	6.7083	3	13
	ER.6	(3.2756, 3.4756, 3.6756)	3.4756	(3.5378, 3.7378, 3.9378)	3.7378	13.0178	2	3

In the FAHP method, consistency was verified using the consistency ratio (CR) metric, as proposed by Gogus and Boucher (1998). The CR values for each main calculation—including comparisons of main factors (cr= 0.072), supply risk factors (cr=0.085), demand risk factors (cr= 0.067), operational risk factors (cr= 0.091), and environmental risk factors (cr= 0.074)—were all below the 0.1 threshold, ensuring the consistency of the fuzzy pairwise comparison matrices.

Identifying Key Capabilities for Each Immediate action Risk

Based on the probability and impact assessments of each identified risk, we positioned them within the impact-probability matrix. As depicted in Figure 4, seven risks (SR2, SR6, SR8, OR10, DR2, ER3, ER6) fall into the high-sensitivity zone, while eleven risks are situated in the medium-sensitivity zone.

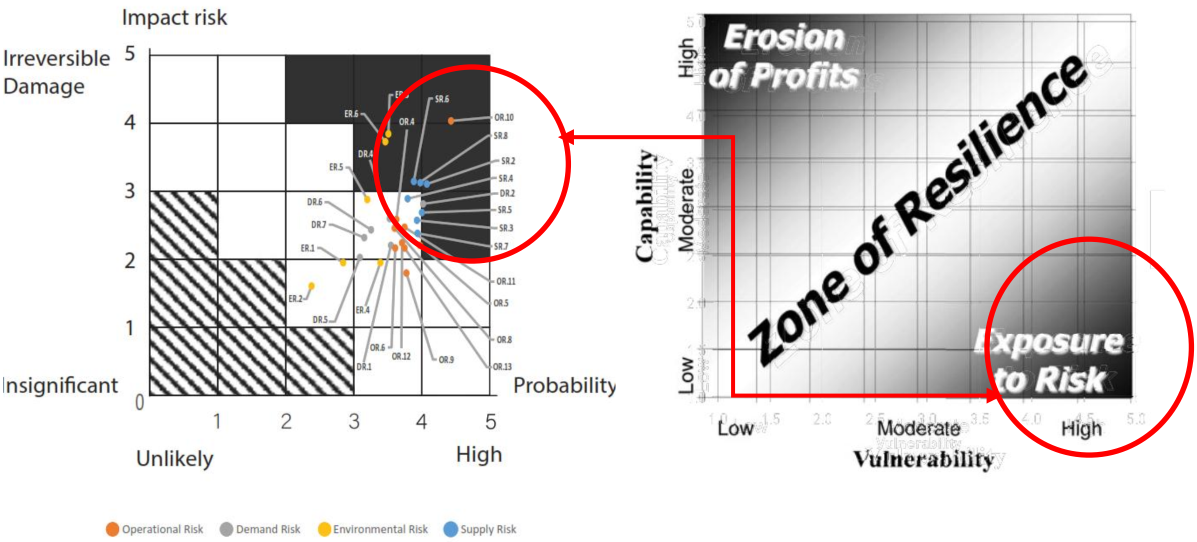

Figure 4. Left - Probability-Impact Matrix Results | Right - Zone of Resilience

Upon identifying the immediate action risks, we extracted the capabilities pertinent to each risk drawing from the frameworks established by Pettit et al. (2011, 2013) and the broader supply chain risk management literature. Building on established theoretical foundations and empirical evidence from prior studies, each immediate action risk was systematically matched to the capabilities most relevant to its mitigation. This literature-grounded mapping allowed us to identify not only the organizational capabilities required to sustain resilience, but also the digitalization tools and technologies that can operationalize these capabilities in practice. As firms increasingly integrate digital solutions into their supply chain operations, aligning capability development with targeted digital investments becomes essential for maintaining the zone of balanced resilience without incurring unnecessary resource expenditure. As presented in Table 5, each high-sensitivity risk is mapped to its corresponding capabilities alongside the digitalization implications that support their development and deployment.

Table 5. Key capabilities and digitalization implications for immediate action risks

Risk	Risk Code	Key Capabilities	Digitalization Implications
Quality Risk	SR2	Supplier evaluation, quality control mechanisms, incoming inspection protocols	Digital quality management systems (QMS), IoT-based real-time quality monitoring, AI-powered defect detection
Supplier Capacity Disruption	SR6	Multi-sourcing strategies, supplier development programs, capacity monitoring	Supply chain visibility platforms, supplier performance dashboards, cloud-based procurement systems
Sourcing Flexibility Risk	SR8	Diversified supplier base, flexible contracting, strategic inventory buffers	Digital procurement platforms, e-sourcing tools, blockchain-enabled supplier verification
Resource Risk	OR10	Resource planning capabilities, alternative material sourcing, inventory optimization	ERP-integrated resource planning, predictive analytics for material demand, digital twin simulations
Market Risk and Competition	DR2	Market intelligence capabilities, demand forecasting, agile product strategy	Big data analytics, AI-driven demand sensing, digital market intelligence tools
Geopolitical Risk	ER3	Geopolitical monitoring, supply chain network diversification, scenario planning	Real-time geopolitical risk monitoring platforms, scenario modeling tools, digital supply network mapping
Macroeconomic and Technological Risk	ER6	Financial hedging capabilities, technology adoption strategy, regulatory compliance	Fintech solutions for currency risk management, technology roadmapping platforms, regulatory compliance software

Discussion and Conclusion

Globally, supply chain risk management has provided a wide range of useful models and frameworks for academics and managers (Sarafan, Squire, & Brandon-Jones, 2019). This article presented a comprehensive classification of automotive parts supply chain risks through an extensive review of the supply chain risk literature. In total, 35 variables were identified, and exploratory factor analysis revealed that 18 subsidiary risks can be classified into four categories. By ranking risks based on the product of relative importance indices for their probability and impact, the priority of risks in each category was determined. The ability to assess and manage supply chain risks effectively has direct implications for firms operating within global supply chains. Identifying the most influential risk factors and aligning them with targeted resilience capabilities enables firms to proactively enhance their participation in global production networks.

Seven key risks fall within the high-sensitivity zone, where both probability and impact exceed level 3: quality risk (SR2), supplier capacity disruption (SR6), sourcing flexibility risk (SR8), resource risk (OR10), market risk and competition (DR2), geopolitical risk (ER3), and macroeconomic and technological risk (SR6). These risks require immediate managerial attention, as their consequences remain difficult to control and can have significant destructive impacts on supply chain performance. Risks in the medium-sensitivity zone require systematic monitoring and planning but can be addressed within routine operational management processes.

The findings of this research enable automotive parts industry managers to consider the sensitivity and priority of risks and develop appropriate strategies to address them. Critically, our analysis demonstrates that digitalization serves as a cross-cutting enabler across all seven immediate action risks. Firms with high exposure to sourcing risks should invest in digital procurement platforms and supplier visibility tools to develop redundancy in their supplier networks and establish stronger contractual agreements. Those facing significant operational and resource risks should leverage ERP-integrated resource planning, predictive analytics, and digital twin simulations to enhance production flexibility and contingency planning. Meanwhile, firms affected by market and demand risks should deploy AI-driven demand sensing and big data analytics to improve forecasting accuracy and adopt agile market strategies. For geopolitical and macroeconomic risks, real-time risk monitoring platforms, scenario modeling tools, and fintech solutions for currency risk management provide firms with the analytical capacity to anticipate disruptions and respond proactively.

An integrated approach to resilience-building necessitates identifying the most significant risk factors affecting supply chain performance and aligning them with appropriate capabilities. The categorization of risks proposed by Thun and Hoenig (2011) provides a useful framework for assessing how different risks impact resilience. When sourcing risks exert the greatest influence, firms should prioritize capabilities such as supplier diversification, multi-sourcing strategies, and collaborative partnerships, supported by digital procurement and blockchain-enabled supplier verification. In cases where manufacturing and resource risks dominate, investing in process flexibility, redundancy, and lean production techniques becomes critical, with digital twins and IoT-based monitoring providing real-time operational intelligence. When delivery and market risks are the primary concern, firms should enhance their visibility through advanced tracking systems, demand forecasting platforms, and logistics optimization tools.

Understanding these relationships allows firms to tailor their global supply chain participation strategies accordingly. Firms seeking to strengthen backward supply chain participation may need to focus on sourcing resilience by securing multiple supply sources and reducing dependency on single suppliers, a process that digital procurement platforms can substantially accelerate. Conversely, firms aiming to expand forward participation should enhance their delivery resilience by improving distribution capabilities and logistics networks through digital visibility solutions. By systematically linking risk categories with resilience capabilities and their corresponding digitalization tools, firms can develop a strategic approach to mitigating supply chain vulnerabilities while sustaining competitiveness in global markets.

Despite these risks, the industry possesses inherent capabilities that can be leveraged to enhance resilience and global competitiveness. To ensure long-term sustainability and successful global supply chain participation, automotive firms must adopt proactive strategies such as diversifying suppliers, investing in technological upgrades, improving quality control processes, and strengthening strategic alliances. The ability to integrate digitalization into these strategies effectively will be a key determinant of how well firms can mitigate supply chain risks and achieve a stable and competitive position within the global market. This study therefore contributes a risk-driven capability development framework that bridges supply chain risk management theory and digitalization practice, offering both academic and managerial value for firms navigating an increasingly uncertain global environment.

Research limitations should also be noted. This study was conducted in the automotive parts industry, and since specific hazards and risks can be identified for each industry, the results may not be directly generalizable to other sectors. Similarly, while supply chain risk management has received extensive attention globally, empirical studies linking risk prioritization to digitalization-driven capability development remain limited, particularly in emerging market contexts. Future studies could examine the applicability of this framework across other industries and geographical contexts, and could explore the extent to which specific digital technologies moderate the relationship between risk exposure and supply chain resilience. Additionally, given the identification of priority risks in this industry, future research could empirically test the effectiveness of the digitalization tools proposed in Table 5 as mitigation mechanisms.

Disclosure of Interest

The author declares no competing interests.

Declaration of Funding

No funding was received for this research.

Data Availability Statement (DAS)

The authors confirm that the data supporting the findings of this study are available upon request.

References

Anguzu, R., & Aila, F. (2024). Sources of Supply Chain Volatility: A Literature Review.

Antràs, P., & Helpman, E. (2004). Global sourcing. Journal of Political Economy, 112(3), 552-580.

Arvis, J. F., Raballand, G., & Marteau, J. F. (2007). *The cost of being landlocked: logistics costs and supply chain reliability* (Vol. 4258). World Bank Publications.

Badhan, I. A., Neeroj, M. H., & Rahman, S. (2024). Currency rate fluctuations and their impact on supply chain risk management: An empirical analysis. *International journal of business and management sciences*, *4*(10), 6-26.

Bak, O. (2018). Supply chain risk management research agenda: from a literature review to a call for future research directions. *Business Process Management Journal*, *24*(2), 567-588.

Baldwin, R. (2016). Globalization's three unbundlings. Harvard University Press.

Behzadi, G., O'Sullivan, M. J., Olsen, T. L., & Zhang, A. (2018). Agribusiness supply chain risk management: A review of quantitative decision models. *Omega*, *79*, 21-42.

Bell, J. E., Autry, C. W., Mollenkopf, D. A., & Thornton, L. M. (2012). A natural resource scarcity typology: theoretical foundations and strategic implications for supply chain management. *Journal of Business Logistics*, *33*(2), 158-166.

Bell, J. E., Mollenkopf, D. A., & Stolze, H. J. (2013). Natural resource scarcity and the closed-loop supply chain: a resource-advantage view. *International Journal of Physical Distribution & Logistics Management*, *43*(5/6), 351-379.

Ben-Faress, M., Elouadi, A., & Gretete, D. (2019). Global Supply Chain Risk Management. *Am. J. Eng. Applied Sci*, *12*(2), 147-155.

Bergek, A., Berggren, C., Magnusson, T., & Hobday, M. (2013). Technological discontinuities and the challenge for incumbent firms: Destruction, disruption or creative accumulation?. *Research Policy*, *42*(6-7), 1210-1224.

Birkinshaw, J. (2023). How incumbent firms respond to emerging technologies: Comparing supply-side and demand-side effects. *California Management Review*, *66*(1), 48-71.

Blome, C., & Schoenherr, T. (2011). Supply chain risk management in financial crises—A multiple case-study approach. *International journal of production economics*, *134*(1), 43-57.

Borin, A., & Mancini, M. (2019). Measuring what matters in global value chains and value-added trade. Policy Research Paper 8804, World Bank, Washington, DC.

Cafaggi, F., & Iamiceli, P. (2015). Contracting in global supply chains and cooperative remedies. *Uniform law review*, *20*(2-3), 135-179.

Cai, Q., & Li, L. (2022). Path selection and optimization of Chinese manufacturing industry participating in global value chain reconstruction. *Sustainability*, *14*(11), 6688.

Caldara, D., & Iacoviello, M. (2022). Measuring geopolitical risk. *American Economic Review*, *112*(4), 1194-1225.

Cao, S., Bryceson, K., & Hine, D. (2021). Collaborative risk management in decentralised multi-tier global food supply chains: an exploratory study. *The International Journal of Logistics Management*, *32*(3), 1050-1067.

Cao, Z. H., Zhou, Y. W., Zhao, J., & Li, C. W. (2015). Entry mode selection and its impact on an incumbent supply chain coordination. *Journal of Retailing and Consumer Services*, *26*, 1-13.

Cheng, C. H. J., & Chiu, C. W. J. (2018). How important are global geopolitical risks to emerging countries?. *International economics*, *156*, 305-325.

Chereau, C., & Schellhorn, C. (2014). Supply chain management and investment risk. *Chereau, C., and Schellhorn, C."Supply Chain Management and Investment Risk," International Journal of Business and Social Science*, *5*(13), 45-52.

Chopra, S., & Sodhi, M. S. (2004a). Supply-chain breakdown. *MIT Sloan management review*, *46*(1), 53-61.

Chopra, S., & Sodhi, M. S. (2004b). Managing risk to avoid supply-chain breakdown. *MIT Sloan management review*.

Christopher, M., & Lee, H. (2004). Mitigating supply chain risk through improved confidence. *International journal of physical distribution & logistics management*, *34*(5), 388-396.

Christopher, M., & Peck, H. (2004). Building the resilient supply chain.

Chukwuka, O. J., Ren, J., Wang, J., & Paraskevadakis, D. (2023). A comprehensive research on analyzing risk factors in emergency supply chains. *Journal of Humanitarian Logistics and Supply Chain Management*, *13*(3), 249-292.

Constantinescu, C., Mattoo, A., Ruta, M., & Constantinescu, I. (2019). Does vertical specialisation increase productivity?. World Economy, 42(8), 2385-2402. https://doi.org/10.1111/twec.12801

Cucchiella, F. , & Gastaldi, M. (2006). Risk management in supply chain: a real option approach. Journal of Manufacturing Technology Management, Journal of Manufacturing Technology Management, 700-720 .

Darnall, N., Welch, E. W., & Cho, S. K. (2019). Sustainable supply chains and regulatory policy. In *Handbook on the sustainable supply chain* (pp. 513-525). Edward Elgar Publishing.

Ebrahimi Kordlar, A. & Mohammadi Shad, Z. (2014). Investigating the Relationship between Default Risk and Earning Response Coefficient (ERC). *Accounting and Auditing Review*, 21(1), 1-18. doi: 10.22059/acctgrev.2014.50780

Ebrahimi Kordlar, A., & Aarabi, M. J. (2010). Ownership concentration and earnings quality in the listed companies in tehran’s stocks exchange. *Journal of financial accounting research*, 2(4), 95-110.

El Baz, J., & Ruel, S. (2021). Can supply chain risk management practices mitigate the disruption impacts on supply chains’ resilience and robustness? Evidence from an empirical survey in a COVID-19 outbreak era. *International journal of production economics*, *233*, 107972.

Elangovan, D., Sundararaj, G., Devadasan, S. R., & Karuppuswamy, P. (2010). Analysis of time delays for loss reduction in an automobile components manufacturing organisation using a proactive supply chain risk management model. *International Journal of Services, Economics and Management*, *2*(3-4), 385-411.

Ellegaard, C. (2008). Supply risk management in a small company perspective. *Supply Chain Management: An International Journal*, *13*(6), 425-434.

El-Sayegh, S. M. (2008). Risk assessment and allocation in the UAE construction industry. *International journal of project management*, *26*(4), 431-438.

Ferdows, K. (2018). Keeping up with growing complexity of managing global operations. *International Journal of Operations & Production Management*, *38*(2), 390-402.

Fernandes, A., Kee, H. L., & Winkler, D. (2020). Determinants of global value chain participation: Cross-country evidence. CESifo Working Paper No. 8270.

Finch, P. (2004). Supply chain risk management. *Supply chain management: an International Journal*, *9*(2), 183-196.

Fischl, M., Scherrer-Rathje, M., & Friedli, T. (2014). Digging deeper into supply risk: a systematic literature review on price risks. *Supply Chain Management: An International Journal*, *19*(5/6), 480-503.

Fornell, C., & Larcker, D. F. (1981). Evaluating structural equation models with unobservable variables and measurement error. Journal of Marketing Research, 18(1), 39-50.

Fornell, C., & Larcker, D. F. (1981). Evaluating structural equation models with unobservable variables and measurement error. *Journal of marketing research*, *18*(1), 39-50.

García-Cutrín, J., & Rodríguez-García, C. (2024). Enhancing Corporate Sustainability through Just-In-Time (JIT) Practices: A Meta-Analytic Examination of Financial Performance Outcomes. Sustainability, 16(10), 4025.

Gereffi, G., & Lee, J. (2012). Why the world suddenly cares about global supply chains. *Journal of supply chain management*, *48*(3), 24-32.

Ghadami, A., Abdsharafat, M., Rostamzadeh, R., & Kazemi Miyangaskary, M., (2026). AI-Powered supply chains: Mapping the future of resilience and sustainability, *Industrial Management Journal*, 18(2), 213- 241. https://doi.org/10.22059/imj.2026.410606.1008286

Ghosh, S., & Jintanapakanont, J. (2004). Identifying and assessing the critical risk factors in an underground rail project in Thailand: a factor analysis approach. *International journal of project management*, *22*(8), 633-643.

Giannakis, M., & Papadopoulos, T. (2016). Supply chain sustainability: A risk management approach. *International journal of production economics*, *171*, 455-470.

Giunipero, L. C., & Aly Eltantawy, R. (2004). Securing the upstream supply chain: a risk management approach. *International journal of physical distribution & logistics management*, *34*(9), 698-713.

Gogus, O., & Boucher, T. O. (1998). Strong transitivity, rationality and weak monotonicity in fuzzy pairwise comparisons. *Fuzzy sets and systems*, *94*(1), 133-144.

Hair Jr, J. F., Black, W. C., Babin, B. J., & Anderson, R. E. (2010). Multivariate data analysis. In *Multivariate data analysis* (pp. 785-785).

Hair, J. F., Black, W. C., Babin, B. J., & Anderson, R. E. (2010). Multivariate Data Analysis (7th ed.). Prentice Hall.

Hallikas, J., Karvonen, I., Pulkkinen, U., Virolainen, V. M., & Tuominen, M. (2004). Risk management processes in supplier networks. *International journal of production economics*, *90*(1), 47-58.

Hamidu, Z., Boachie-Mensah, F. O., & Issau, K. (2023). Supply chain resilience and performance of manufacturing firms: role of supply chain disruption. Journal of manufacturing technology management, 34(3), 361-382.

Hummels, D., Ishii, J., & Yi, K-M. (2001). The nature and growth of vertical specialization in world trade. Journal of International Economics, 54, 75-96.

Ivanov, D., & Dolgui, A. (2020). Viability of intertwined supply networks: extending the supply chain resilience angles towards survivability. A position paper motivated by COVID-19 outbreak. *International journal of production research*, *58*(10), 2904-2915.

Jiang, B., Baker, R. C., & Frazier, G. V. (2009). An analysis of job dissatisfaction and turnover to reduce global supply chain risk: Evidence from China. *Journal of operations management*, *27*(2), 169-184.

Jüttner, U., Peck, H., & Christopher, M. (2003). Supply chain risk management: outlining an agenda for future research. *International Journal of Logistics: research and applications*, *6*(4), 197-210.

Jüttner, U., Peck, H., & Christopher, M. (2003). Supply chain risk management: outlining an agenda for future research. *International Journal of Logistics: research and applications*, *6*(4), 197-210.

Kaiser, H. F. (1974). An index of factorial simplicity. Psychometrika, 39(1), 31-36.

Ke, J. Y. F., Shabbir, T., & Corona, J. (2018). The impact of exchange rate volatility on the industry-level geographic diversification of global supply chain network. *International Journal of Logistics Economics and Globalisation*, *7*(4), 366-387.

Kee, H. L., & Tang, H. (2016). Domestic value added in exports: Theory and firm evidence from China. American Economic Review, 106(6), 1402-1436.

Kleindorfer, P. R., & Saad, G. H. (2005). Managing disruption risks in supply chains. *Production and operations management*, *14*(1), 53-68.

Klibi, W., Trepte, K., & Rice Jr, J. B. (2024). Make smarter investments in resilient supply chains. MIT Sloan Management Review, 66(1), 53-57.

Koopman, R., Wang, Z., & Wei, S. (2014). Tracing value-added and double counting in gross exports. American Economic Review, 104(2), 459-94.

Kusrini, E., Sugito, E., Rahman, Z. M., Setiawan, T. N., & Hasibuan, R. P. (2020). Risk mitigation on product distribution and delay delivery: A case study in an Indonesian manufacturing company. In *IOP conference series: materials science and engineering* (Vol. 722, No. 1, p. 012015). IOP Publishing.

Lavastre, O., Gunasekaran, A., & Spalanzani, A. (2012). Supply chain risk management in French companies. *Decision Support Systems*, *52*(4), 828-838.

Liu, Z., Lai, M., Zhou, T., & Zhou, Y. (2009). A supply chain risk assessment model based on multistage influence diagram. In *2009 6th International Conference on Service Systems and Service Management* (pp. 72-75). IEEE.

Manuj, I., & Mentzer, J. T. (2008a). Global supply chain risk management strategies. *International journal of physical distribution & logistics management*, *38*(3), 192-223.

Manuj, I., & Mentzer, J. T. (2008b). Global supply chain risk management. *Journal of business logistics*, *29*(1), 133-155.

Manuj, I., Esper, T. L., & Stank, T. P. (2014). Supply chain risk management approaches under different conditions of risk. *Journal of Business Logistics*, *35*(3), 241-258.

Mason-Jones, R., & Towill, D. R. (1998). Shrinking the supply chain uncertainty circle. *IOM control*, *24*(7), 17-22.

Matook, S., Lasch, R., & Tamaschke, R. (2009). Supplier development with benchmarking as part of a comprehensive supplier risk management framework. *International journal of operations & production management*, *29*(3), 241-267.

Meixell, M. J., & Gargeya, V. B. (2005). Global supply chain design: A literature review and critique. *Transportation Research Part E: Logistics and Transportation Review*, *41*(6), 531-550.

Mentzer, J. T., DeWitt, W., Keebler, J. S., Min, S., Nix, N. W., Smith, C. D., & Zacharia, Z. G. (2001). Defining supply chain management. *Journal of Business logistics*, *22*(2), 1-25.

Mitchell, V. W. (1995). Organizational risk perception and reduction: a literature review. *British Journal of Management*, *6*(2), 115-133.

Mitra, A., & Sarkar, S. (2022). Efficient Supply Chain Contracting with Loss-averse Players in Presence of Multiple Plausible Breaches. *American Business Review*, *25*(2), 3.

Narasimhan, R., & Talluri, S. (2009). Perspectives on risk management in supply chains. *Journal of operations management*, *27*(2), 114-118.

Norozi, M., Nilipour tabatabaei, s., (2026). An integrated PMBOK-based mixed-integer optimization framework for rescue-robot projects, *Industrial Management Journal*, 18(3), 150-181. https://doi.org/10.22059/imj.2026.412066.1008297

Norrman, A., & Jansson, U. (2004). Ericsson's proactive supply chain risk management approach after a serious sub-supplier accident. *International journal of physical distribution & logistics management*, *34*(5), 434-456.

Nunn, N. (2007). Relationship-specificity, incomplete contracts, and the pattern of trade. Quarterly Journal of Economics, 122(2), 569-600.

Nunnally, J. C., & Bernstein, I. H. (1994). Psychometric Theory (3rd ed.). McGraw-Hill.

Nunnally, J. C., & Bernstein, I. H. (1994). Psychometric Theory, 3r ed., McGraw-Hill, New York, NY.

Oke, A., & Gopalakrishnan, M. (2009). Managing disruptions in supply chains: A case study of a retail supply chain. *International journal of production economics*, *118*(1), 168-174.

Olson, D. L., & Wu, D. D. (2010). A review of enterprise risk management in supply chain. Kybernetes, 39(5), 694-706.

Pellegrino, R., Gaudenzi, B., & Zsidisin, G. A. (2024). Mitigating foreign exchange risk exposure with supply chain flexibility: A real option analysis. *Journal of Business Logistics*, *45*(1), e12338.

Peng, M., Peng, Y., & Chen, H. (2014). Post-seismic supply chain risk management: A system dynamics disruption analysis approach for inventory and logistics planning. *Computers & Operations Research*, *42*, 14-24.

Petersen, K. J., Handfield, R. B., & Ragatz, G. L. (2005). Supplier integration into new product development: coordinating product, process and supply chain design. Journal of operations management, 23(3-4), 371-388.

Pettit, T. J., Croxton, K. L., & Fiksel, J. (2013). Ensuring supply chain resilience: development and implementation of an assessment tool. *Journal of business logistics*, *34*(1), 46-76.

Rinaldi, M., Murino, T., Gebennini, E., Morea, D., & Bottani, E. (2022). A literature review on quantitative models for supply chain risk management: Can they be applied to pandemic disruptions?. *Computers & Industrial Engineering*, *170*, 108329.

Romalis, J. (2004). Factor proportions and the structure of commodity trade. American Economic Review, 94(1), 67-97.

Schoenherr, T., & Swink, M. (2015). The roles of supply chain intelligence and adaptability in new product launch success. *Decision Sciences*, *46*(5), 901-936.

Scholten, K., Sharkey Scott, P., & Fynes, B. (2014). Mitigation processes–antecedents for building supply chain resilience. *Supply Chain Management: An International Journal*, *19*(2), 211-228.

Shahsavari, M., Hussain, O. K., Saberi, M., & Sharma, P. (2024). Event identification for supply chain risk management through news analysis by using large language models. The Review of Socionetwork Strategies, 18(2), 255-278.

Sheffi, Y., & Rice Jr, J. B. (2005). A supply chain view of the resilient enterprise. *MIT Sloan management review*.

Souter, G. (2000). Risks from supply chain also demand attention. *Business insurance*, *34*(20), 26-28.

Sreedevi, R., & Saranga, H. (2017). Uncertainty and supply chain risk: The moderating role of supply chain flexibility in risk mitigation. International Journal of Production Economics, 193, 332-342.

Stevens, J. P. (2002). Applied Multivariate Statistics for the Social Sciences (4th ed.). Lawrence Erlbaum Associates.

Tabachnick, B. G., & Fidell, L. S. (2013). Using Multivariate Statistics (6th ed.). Pearson.

Tabrizi, B. H., & Razmi, J. (2013). Introducing a mixed-integer non-linear fuzzy model for risk management in designing supply chain networks. *Journal of Manufacturing Systems*, *32*(2), 295-307.

Tan, K. H., Tse, Y. K., & Chen, J. (2014). Quality risk in global supply networks. Global Supply Chain Quality Management: Product Recalls and Their Impact. Taylor & Francis.

Tang, C. S. (2006). Perspectives in supply chain risk management. *International journal of production economics*, *103*(2), 451-488.

Tang, O., & Musa, S. N. (2011). Identifying risk issues and research advancements in supply chain risk management. *International journal of production economics*, *133*(1), 25-34.

Teece, D. J., Pisano, G., & Shuen, A. (1997). Dynamic capabilities and strategic management. *Strategic management journal*, *18*(7), 509-533.

Thun, J. H., & Hoenig, D. (2011). An empirical analysis of supply chain risk management in the German automotive industry. *International journal of production economics*, *131*(1), 242-249.

Tomlin, B. (2006). On the value of mitigation and contingency strategies for managing supply chain disruption risks. *Management science*, *52*(5), 639-657.

Tummala, R., & Schoenherr, T. (2011). Assessing and managing risks using the supply chain risk management process (SCRMP). *Supply Chain Management: An International Journal*, *16*(6), 474-483.

Um, J., & Han, N. (2021). Understanding the relationships between global supply chain risk and supply chain resilience: the role of mitigating strategies. *Supply Chain Management: An International Journal*, *26*(2), 240-255.

Wagner, S. M., & Bode, C. (2008). An empirical examination of supply chain performance along several dimensions of risk. *Journal of business logistics*, *29*(1), 307-325.

Wang, Z., Wei, S., Yu, X., & Zhu, K. (2016). Characterizing global value chains. Working Paper.

Xu, P., & Xiao, T. (2023). Entry deterrence strategies for an incumbent supply chain in the presence of inertial consumer and optimistic entrant. *International Transactions in Operational Research*.

Yi, K-M. (2003). Can vertical specialization explain the growth of world trade? Journal of Political Economy, 111(1), 52-102.

Zhu, Q., Sarkis, J., & Lai, K. H. (2017). Regulatory policy awareness and environmental supply chain cooperation in China: A regulatory-exchange-theoretic perspective. *IEEE Transactions on Engineering Management*, *65*(1), 46-58.

Bibliographic information of this paper for citing:

Zarea, Hadi; Moghaddamzadeh, Hadi; Moradi, Mahmoud; Hassani, Abdeslam; Warin, Thierry & Stojkov, Aleksandar (2026). Risk-Driven Capability Development in Global Supply Chain Resilience: Implications for Digitalization. *Journal of Information Technology Management*, 18 (3), 82-107. https://doi.org/10.22059/jitm.2026.414800.4475