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Technology or innovation alone is not enough: A *SEM-fsQCA* based study on intelligent automation driven supply chain resilience

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ABSTRACT

In an era marked by increasing disruption and digital transformation, this study explores how Intelligent Automation (IA) contributes to Supply Chain Resilience (SCR), with particular attention to the mediating roles of Integrability and Visibility. Despite growing interest in digital supply chain capabilities, limited empirical evidence exists on how advanced technologies such as artificial intelligence, machine learning, and robotic process automation translate into resilience, especially in the context of emerging economies. Grounded in the Technology-Organization-Environment (TOE) framework, the study employs a mixed-method approach by integrating Partial Least Squares Structural Equation Modeling (PLS-SEM) and fuzzy-set Qualitative Comparative Analysis (fsQCA). Data were collected from 312 manufacturing firms in Lithuania, representing a digitally transforming economy with unique structural and institutional conditions. The PLS-SEM results confirm that IA significantly enhances SCR, primarily through the mediating effect of Integrability. While IA also improves supply chain visibility, the mediating role of Visibility in the IA-SCR relationship is not supported, suggesting that transparency alone is insufficient to enable resilience. Complementing these findings, the fsQCA results reveal that multiple configurations can lead to high resilience. The combination of IA and Integrability consistently emerged as a sufficient pathway, regardless of the presence or absence of Visibility. Moreover, firms without advanced IA capabilities but with strong integration and visibility were also able to achieve resilient outcomes, offering viable alternatives for resource-constrained environments. These insights underscore that resilience is not driven by technology adoption alone, but by the strategic configuration and alignment of digital capabilities. This study contributes to the literature by integrating variance-based and configurational perspectives, offering a more nuanced and context-sensitive understanding of digital transformation outcomes. It challenges the assumption that visibility is inherently sufficient for resilience and highlights the importance of integrability as a foundational enabler. The findings hold theoretical and practical value for building resilient, adaptive supply chains in emerging economy settings.

Introduction

Supply chain resilience (SCR) is critical for organizations amid an increasingly volatile global market. Resilience in supply chains refers to a firm's ability to absorb, recover from, and adapt to disruptions while maintaining essential operations and long-term sustainability (Christopher & Peck, 2004). As supply chains grow more complex, globally interconnected, and exposed to multiple risks, resilience has emerged as a key determinant of competitive advantage (Pettit et al., 2010). Traditional supply chain systems, while designed for efficiency, are often ill-equipped to handle the increasingly frequent disruptions caused by economic crises, geopolitical instability, and natural disasters (Sheffi & Rice, 2005). This has led to a growing recognition of the need for supply chains that are not only efficient but also flexible, adaptable, and responsive to unforeseen shocks (Hohenstein et al., 2015). The challenges of traditional supply chains, particularly amid global disruptions, have become more apparent in recent years. The COVID-19 pandemic, for example, exposed vulnerabilities in supply chains across industries, as firms were unable to swiftly pivot or adapt due to rigid, siloed systems (Choi, Rogers, & Vakil, 2020). Such disruptions often reveal the shortcomings of traditional approaches to supply chain management, in which processes are optimized for cost efficiency and speed but lack the flexibility to respond to sudden changes (Ivanov, 2020). Consequently, organizations are increasingly focusing on

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building resilient supply chains capable of withstanding disruptions and minimizing operational downtime. The challenge, however, lies in designing and implementing systems that can balance the competing demands of efficiency and resilience (Lee, 2004).

Intelligent automation (IA) offers a promising solution to enhancing SCR by integrating advanced technologies such as artificial intelligence (AI), robotic process automation (RPA), and machine learning (ML). Unlike traditional automation systems that focus on task-level efficiency, IA enables the end-to-end automation and integration of complex processes across supply chains, improving agility, visibility, and decision-making capabilities (Ng et al., 2021). IA technologies can provide real-time data analytics, predictive capabilities, and autonomous decision-making, all of which contribute to a supply chain's ability to respond to disruptions more effectively (Lacity & Willcocks, 2021). For instance, IA can dynamically adjust production schedules, reconfigure logistics routes, and optimize inventory levels in response to external changes, providing the necessary flexibility to handle disruptions (Jha et al., 2021). The integration of AI and RPA can enable proactive risk management, early warning systems, and rapid adjustments, all of which are crucial for enhancing SCR (Anagnoste, 2018). While existing research has examined the role of digital transformation and Industry 4.0 technologies, such as AI and blockchain, in enhancing SCR, few studies have specifically addressed IA as a holistic, integrated framework. Previous studies have primarily focused on individual technologies, investigating their isolated impacts on supply chain performance and resilience (Jin et al., 2024). While these technologies offer significant benefits, their integration into the IA framework provides an opportunity to leverage synergies among AI, RPA, and other emerging technologies, thereby offering a more comprehensive solution to enhance SCR (Ghosh, 2021; Mubarik et al., 2025). IA's capacity to integrate the strengths of various digital tools into a unified system offers a more adaptive and proactive approach to supply chain management than individual technologies (Dahl et al., 2022).

Therefore, this study aims to explore the role of IA in improving SCR by examining its ability to integrate diverse technologies into a cohesive framework that can autonomously respond to disruptions. It will investigate the mediating role of integration capability in the relationship between IA and SCR and examine how digitalization-related technical competency moderates this relationship. By addressing the gap in the literature regarding the specific impact of IA on SCR, this study will contribute valuable insights for both academia and industry.

Despite substantial advances in digital supply chain research, very few studies have examined IA as an integrated construct that holistically encompasses AI, RPA, and ML, and their systemic effects on resilience. Existing studies have often treated these technologies in isolation, exploring their individual operational benefits rather than their synergistic, system-level potential to enable autonomous, adaptive supply chains (Coombs et al., 2020; Ng et al., 2021; Ghobakhloo et al., 2024). This fragmented view overlooks the fact that IA represents a new generation of digital capability, one that integrates sensing, decision, and execution functions across end-to-end supply chain processes

Moreover, most empirical evidence on digital transformation and resilience originates from developed economies, where firms possess advanced digital infrastructures and institutional maturity (Ghobakhloo & Ng, 2019; Lacity & Willcocks, 2021). Consequently, there is limited understanding of how IA operates in emerging economies, where organizational readiness, technical competencies, and environmental pressures differ markedly. Additionally, prior studies have relied predominantly on variance-based, linear methods, which may not fully capture the configurational complexity and complementarity of digital capabilities that jointly drive resilience outcomes.

To address these research gaps, the present study conceptualizes IA as an integrated, multi-technology construct and examines its impact on SCR through the mediating roles of integrability and visibility. Grounded in the Technology-Organization-Environment (TOE) framework and informed by the absorptive capacity-based view (Zahra & George, 2002; Todorova & Durisin, 2007), this research adopts a hybrid empirical design that combines Partial Least Squares Structural Equation Modeling (PLS-SEM) and fuzzy-set Qualitative Comparative Analysis (fsQCA). This dual-method approach enables the exploration of both linear effects and configurational pathways, thereby capturing the multidimensional nature of digital transformation and resilience.

Accordingly, the study addresses the following research questions to guide the analysis:

(RQ1) How does Intelligent Automation (IA) enhance Supply Chain Resilience (SCR)?
(RQ2) What are the mediating roles of Integrability and Visibility in the IA–SCR relationship?
(RQ3) Under what configurations of digital capabilities does resilience emerge in digitally transforming economies?

Theoretical background

The study of IA in the context of SCR requires a solid theoretical framework to explore the factors that shape the adoption and effectiveness of IA technologies. TOE is one of the most suitable frameworks for examining the intersection of technology, organizations, and external pressures. This framework, developed by Tornatzky and Fleischer (1990), posits that the adoption of a new technology is influenced by three primary contexts: technological, organizational, and environmental. These contexts facilitate a holistic understanding of how organizations decide to implement and integrate new technologies. In the case of IA, this framework is particularly relevant because it encompasses advanced technologies such as AI, ML, and RPA, which collectively contribute to the development of IA systems.

The technological context focuses on the characteristics of the technology itself, including its relative advantage, compatibility with existing systems, complexity, and trialability. In the case of IA, the technological context is essential, encompassing interconnected technologies that automate complex supply-chain tasks and processes. These technologies offer several potential benefits, such as operational efficiency, enhanced decision-making, and real-time data processing, which can significantly improve SCR (Lacity & Willcocks, 2021; Ghosh, 2021). However, the complexity of integrating IA technologies into existing supply chain systems could act as a barrier for firms, particularly if they lack the necessary technical infrastructure or expertise. The adoption of IA in supply chains depends on the perceived advantages of these technologies and the firm's ability to manage and integrate them effectively. Ng et al. (2021) emphasize that while IA offers great promise for improving efficiency, organizations need to ensure that the technology is compatible with their existing systems and delivers a clear return on investment.

The organizational context, including internal factors such as organizational culture, resources, and readiness for technological change, also plays a significant role in IA adoption. A key aspect of this context is the organization's preparedness to implement and sustain digital transformation. For a supply chain to leverage IA technologies, firms must ensure they have the necessary resources, including skilled personnel and financial capital. Furthermore, the organization's culture must be open to innovation and change, with leadership committed to advancing digital initiatives. The organizational capability to manage and integrate IA into existing operations is crucial in determining the speed and success of the technology's adoption. Firms with a strong digital transformation strategy and a readiness to innovate are more likely to successfully incorporate IA technologies into their supply chains, thereby improving resilience and operational continuity (Coombs et al., 2020). Organizational readiness and leadership support have been identified as critical factors for the successful deployment of IA, particularly in complex supply chains (Josyula et al., 2021).

The environmental context refers to external factors that influence technology adoption, such as market dynamics, competitive pressures, and regulatory requirements. In supply chains, the environmental context is crucial, as external pressures often necessitate greater resilience. Globalization and the increasing complexity of supply chains have amplified the challenges in maintaining operational continuity. Events such as the COVID-19 pandemic or natural disasters highlight the vulnerabilities of traditional supply chains and underscore the need for more resilient systems (Coombs et al., 2020; Lacity & Willcocks, 2021). Regulatory frameworks, including sustainability and digital transformation mandates, further incentivize organizations to adopt innovative technologies (Ghosh, 2021). In such an environment, external pressures to maintain supply chain efficiency and continuity induce firms to invest in IA technologies, thereby enhancing their agility, responsiveness, and capacity to handle disruptions. Josyula et al. (2021) indicate that external market pressures and regulations are key drivers for the adoption of digital and intelligent technologies in supply chains.

By applying the TOE framework to the context of IA in supply chains, we can obtain insights into how IA contributes to SCR. The technological context emphasizes how the features of IA technologies, such as predictive analytics and automation of routine tasks, can enhance supply chain flexibility and responsiveness (Lacity & Willcocks, 2021; Ghosh, 2021). Organizational readiness is crucial to the successful adoption of IA, as firms must align their internal processes and capabilities with the integration of new technologies (Josyula et al., 2021). Finally, external pressures, including competitive forces and market volatility, drive the urgency for adopting IA to ensure SCR (Coombs et al., 2020). The TOE framework provides a comprehensive understanding of the factors that influence IA adoption, making it an essential tool for analyzing IA's role in enhancing SCR.

Literature review

Supply chain resilience

Owing to the increasing volatility, uncertainty, complexity, and ambiguity (VUCA) of modern supply chains (Christopher & Peck, 2004), SCR has become increasingly significant among researchers and practitioners. SCR refers to a supply chain's ability to adapt to and recover from disruptions, ensuring the continuity of core functions while maintaining or improving performance outcomes (Ponomarov & Holcomb, 2009). Supply chain disruptions—owing to natural disasters, geopolitical tensions, pandemics, and other factors—have underscored the importance of resilience in maintaining operational stability (Ivanov, 2020). In the current globalized economy, supply chains are often characterized by interdependencies, rendering them susceptible to cascading disruptions that can reverberate across industries and regions.

Traditional supply chains have been primarily designed to emphasize efficiency, cost minimization, and just-in-time inventory systems. While these features are essential for operational performance, they often reduce supply chain agility and its adaptability to disruptions (Heckmann et al., 2015). This lack of resilience was particularly evident during the COVID-19 pandemic, which exposed vulnerabilities in global supply chains and their inability to recover swiftly from disruptions (Brandon-Jones et al., 2014). Consequently, businesses increasingly recognize the need for resilient supply chains that can absorb sudden disruptive shocks and rapidly adapt to maintain operational continuity (Soni et al., 2021).

In recent years, scholars have emphasized building resilience through flexibility, redundancy, and responsiveness to unforeseen changes (Hohenstein et al., 2015). According to Chopra and Sodhi (2004), firms with resilient supply chains can better manage risk, mitigate the impact of disruptions, and maintain operational continuity. Resilient supply chains leverage technologies such as big data analytics, cloud computing, and AI to enhance visibility, streamline decision-making, and improve their ability to anticipate and respond to disruptions (Chong et al., 2017). Recent research highlights the role of digital technologies in improving SCR, suggesting that integrating Industry 4.0 technologies, such as AI and IoT, enhances supply chain visibility, enabling firms to rapidly identify and respond to risks (Zhang et al., 2020).

Incorporating IA into supply chains can promote resilience by enabling faster decision-making, automating routine processes, and providing real-time insights into supply chain performance. IA technologies can help reduce human error, enhance predictive capabilities, and increase the agility of supply chain operations (Lacity & Willcocks, 2021). As such, IA's role in enhancing SCR is increasingly recognized in the literature as it facilitates a holistic approach to address the challenges of modern supply chains (Coombs et al., 2020).

Building on this understanding of resilience as a dynamic capability, recent research suggests that digital transformation technologies provide the technical foundation for sensing, responding, and adapting to disruptions (Ivanov & Dolgui, 2020; Wamba et al., 2020). Among these technologies, IA has emerged as a particularly promising enabler of resilience, integrating AI, ML, and automation to enhance agility and real-time decision-making across supply chain networks. The following subsection explores the role of IA as a systemic digital capability that underpins resilient performance.

Intelligent automation

Additionally, IA plays a critical role in enhancing decision-making processes by providing real-time data and automating routine tasks that would otherwise consume valuable human resources. This, in turn, enables businesses to focus on more strategic and high-value activities that contribute to resilience, such as risk mitigation and contingency planning (Lacity et al., 2021). The integration of RPA into business operations is another key aspect of IA, as it enables organizations to automate complex workflows, reducing lead times and operational costs while improving process efficiency and accuracy (Jha et al., 2021).

However, the successful implementation of IA in supply chains requires substantial investment in technology, skilled labor, and organizational readiness (Ghosh, 2021). According to Attaran (2023), organizations must possess a certain degree of digital maturity and technical competency to effectively implement IA solutions. Without this, businesses may face challenges integrating IA with legacy systems and business processes, thereby limiting its potential to enhance SCR.

Recent studies emphasize that IA has the potential to transform supply chain operations by enabling smarter, more adaptive systems that can respond dynamically to changes in demand, supply, and market conditions (Lacity et al., 2021). As organizations increasingly apply IA to enhance SCR, it is crucial to identify the factors that influence the successful implementation of these technologies and how they interact with other organizational capabilities.

While IA enhances operational intelligence and responsiveness, its effectiveness in building resilience depends on the mechanisms for sharing, synchronizing, and making information and processes transparent. Two interrelated capabilities: integrability and visibility, serve as the key conduits through which IA influences supply chain outcomes. The following subsection examines how visibility, as an informational capability, translates IA-driven data insights into situational awareness and proactive risk mitigation.

Visibility in supply chain resilience

Supply chain visibility has emerged as a foundational capability in enhancing SCR, particularly in an era marked by VUCA. Visibility refers to a firm's ability to track and monitor the flow of goods, information, and finances across all tiers of the supply chain in real or near-real time. It enables organizations to detect disruptions early, anticipate risks, and respond proactively, making it a key enabler of SC resilience (Choi et al., 2020; Mubarik et al., 2021). Visibility is not merely a supportive function but a strategic lever for resilience (Pettit, Fiksel, & Croxton, 2010). Mubarik et al. (2021) argue that visibility enables firms to zoom into tier 2, or even tier 3, suppliers and assess vulnerabilities before they escalate into full-blown disruptions. By mapping upstream, midstream, and downstream processes and rendering them visible, firms can identify bottlenecks, forecast delays, and realign resources swiftly—these constitute the core tenets of resilience. Visibility transforms mapping into actionable insights, which, in turn, enhances the dimensions of organizational readiness, responsiveness, and recovery capabilities that are critical to resilience (Pettit, Fiksel, & Croxton, 2010).

In the context of technological integration, visibility is increasingly driven by digital tools such as blockchain, IoT, and real-time analytics. This technological augmentation not only improves transparency but also facilitates data-driven decision-making during disruptions. Importantly, visibility supports cleaner, more sustainable production by enhancing transparency and accountability across the supply chain, thereby driving proactive compliance with environmental, social, and governance (ESG) criteria.

Integrability

Integrability is a critical factor for the successful implementation of IA within existing organizational frameworks. IA technologies require seamless integration with both legacy systems and new technologies across an organization's value chain. In the context of SCR, integrability refers to IA systems' ability to connect with various components of the supply chain, such as back-end systems, business processes, and enterprise resource planning (ERP) systems, to create a cohesive, integrated technological ecosystem (Coombs et al., 2020). The ability of IA systems to integrate with existing technologies and processes is vital for enabling real-time data flow, supporting decision-making, and automating routine tasks. Recent studies have emphasized the importance of technology integrability for the successful adoption of Industry 4.0 technologies, including AI and RPA, within supply chains. Josyula et al. (2021) found that a lack of integrability can be a significant barrier to the adoption of AI and automation technologies, particularly in industries with complex and outdated IT infrastructures. Integrability challenges arise when IA systems cannot interface with existing systems or processes, leading to inefficiencies and diminished functionality. For example, Kjoersvik & Bate (2022) highlighted that the inability to integrate new IA systems with legacy technologies could limit the potential benefits of IA in enhancing SCR.

Moreover, IA systems must provide end-to-end integration across the supply chain, from procurement and production to logistics and distribution (Coombs et al., 2020). Vertical integration of IA systems across business components, such as supply chain processes, operators, and enterprise systems, is essential for optimizing performance and improving resilience. IA solutions that offer both horizontal and vertical integration afford businesses the agility to respond to disruptions, enhance decision-making, and optimize resources across the supply chain (Jha et al., 2021).

Collectively, these four constructs constitute an interconnected capability system. IA provides the technological foundation for digital sensing and decision-making; integrability ensures seamless interconnection of systems and processes; visibility delivers real-time situational awareness; and resilience emerges as the adaptive outcome of their alignment. Viewed through the lens of absorptive capacity (Cohen & Levinthal, 1990; Zahra & George, 2002; Todorova & Durisin, 2007), these capabilities collectively enhance a firm's ability to acquire, assimilate, and exploit digital knowledge to respond effectively to disruptions. This integrative perspective underscores that resilience is not a product of individual technologies but of their synergistic configuration within digitally connected ecosystems.

Hypotheses development

Intelligent automation and supply chain resilience

The role of Intelligent Automation (IA), which integrates technologies such as artificial intelligence (AI), machine learning (ML), and robotic process automation (RPA), has gained increasing attention as a transformative factor in improving organizational resilience, particularly within supply chain management. Supply chain resilience (SCR) refers to a firm's ability to adapt to and recover from disruptions, and IA plays a pivotal role in this regard by enabling real-time monitoring, optimization, and rapid decision-making (Ghobkhloo & Ng, 2019). By leveraging IA technologies, firms can enhance their supply chain's ability to respond to both planned and unplanned disruptions, such as natural disasters, geopolitical shifts, or supply chain bottlenecks (Jha *et al.*, 2021).

The core mechanisms through which IA contributes to SCR include enhanced decision-making through data analytics, autonomous processes, and predictive capabilities. AI, for example, provides supply chains with the ability to forecast disruptions and automatically take pre-emptive actions, such as rerouting shipments or adjusting inventory levels, to prevent adverse impacts (Attaran, 2023). These technologies allow firms to maintain continuity during supply chain disruptions, thereby minimizing operational downtime and mitigating the effects of disruptions. According to Coombs *et al.* (2020), AI-driven automation tools allow for the continuous assessment of risk scenarios, enabling organizations to respond proactively and with greater precision to disruptions in supply chains. Moreover, IA can provide real-time visibility into every aspect of the supply chain, thus improving the agility and flexibility needed to make quick adjustments (Zhang *et al.*, 2025).

Furthermore, the adoption of IA can enhance collaboration and communication within the supply chain ecosystem, making it easier to share data across partners and suppliers (Lacity & Willcocks, 2021). Through integrated platforms powered by IA, organizations are better positioned to manage uncertainties and respond to shifting demands. In this context, firms that successfully adopt IA technologies are likely to experience higher levels of resilience due to their ability to adjust quickly and effectively to change.

Based on these mechanisms, it is hypothesized that:

H1. *The adoption of Intelligent Automation (IA) positively influences Supply Chain Resilience (SCR).*

Integrability, intelligent automation (IA) and supply chain resilience (SCR)

Integrability, defined as the seamless connection between new IA technologies and existing information and operations technologies (IT and OT), is crucial to maximizing the potential benefits of IA in supply chains. IA solutions, such as AI-driven tools, must be integrated effectively with legacy systems to allow for streamlined data flow and decision-making (Jha *et al.*, 2021). The ability to integrate IA technologies with existing infrastructure and systems enables businesses to operate more efficiently and respond more quickly to supply chain disruptions (Coombs *et al.*, 2020). This integration allows for improved data-sharing capabilities across different levels of the supply chain, ensuring real-time insights and enhancing responsiveness.

The significance of integrability has been widely discussed in the literature. For instance, in the context of Industry 4.0, Jha *et al.* (2021) argue that the failure to achieve smooth integration of new technologies with existing systems often leads to inefficiencies and a slower response to disruptions. Conversely, successful integration of IA technologies with legacy systems has been shown to lead to enhanced operational flexibility, better decision-making, and, ultimately, increased resilience (Kjoersvik & Bate, 2022). Integrating IA with supply chain management systems also facilitates real-time visibility, which allows for more accurate forecasting and improved response times to supply chain disruptions (Lacity & Willcocks, 2021).

Integrability also enables organizations to develop cohesive digital ecosystems that facilitate data exchange and the optimization of processes across different supply chain functions. This end-to-end integration of systems and processes enables a more agile and flexible response to changes in the market or disruptions within the supply chain (Ghobkhloo & Ng, 2019). For example, by integrating AI-based demand forecasting systems with existing inventory management tools, companies can respond quickly to changing customer demands, thus enhancing resilience during market fluctuations.

Given these considerations, it is hypothesized that integrability plays a critical mediating role in enhancing the relationship between IA adoption and supply chain resilience. Thus, the second hypothesis is:

H2. *The integrability of Intelligent Automation (IA) with existing systems mediates the relationship between IA and Supply Chain Resilience (SCR).*

Visibility, intelligent automation (IA) and supply chain resilience (SCR)

Visibility enables firms to detect risks early, assess disruptions accurately, and coordinate timely responses across organizational tiers (Mubarik et al., 2021; Ivanov & Dolgui, 2020). Intelligent Automation enhances this capability by integrating real-time sensors, analytics, and decision-support systems into supply chain operations, thereby improving situational awareness and the speed of coordinated action. While prior studies consistently regard visibility as a key element of digital supply chains, empirical evidence on its direct effect on resilience remains mixed. Some research reports that enhanced visibility improves responsiveness and recovery (Pettit et al., 2010; Kusi-Sarpong et al., 2021), whereas others indicate that transparency alone is insufficient to guarantee resilient performance without complementary integration or agility mechanisms (Ivanov & Dolgui, 2020; Mubarik et al., 2023).

Against this background, the present study contributes by theoretically reconciling these divergent findings through the lens of Intelligent Automation. We argue that IA does not foster resilience solely through technological transparency but through the quality and configurational alignment of visibility with integrability and decision autonomy. These framing positions visibility not as an outcome variable but as a mediating capability, a transmission mechanism through which IA-driven data analytics and automation enhance a supply chain's adaptive capacity. Testing this relationship allows us to determine whether IA-enabled visibility independently contributes to resilience or whether its impact depends on complementary integration capabilities, thereby addressing the existing ambiguity in the literature.

Accordingly, we hypothesize that:

H3. Supply chain visibility mediates the relationship between Intelligent Automation (IA) and Supply Chain Resilience (SCR).

Conceptual framework

The conceptual model presented in Fig. 1, for this study aims to examine the interrelationships between Intelligent Automation (IA), Supply Chain Resilience (SCR), Integrability, and Digitalization Technical Competency. According to Hypothesis 1, IA is expected to have a direct positive impact on SCR, as the integration of advanced technologies like AI and robotic process automation enhances operational efficiency, adaptability, and real-time decision-making, thereby strengthening supply chain resilience (Almeida, 2023). Hypothesis 2 introduces Integrability as a mediator in this relationship, suggesting that the effectiveness of IA in improving SCR is contingent upon the seamless integration of IA technologies with existing IT infrastructure and enterprise systems (Xia *et al.*, 2021; Zhang *et al.*, 2025). In other words, the full potential of IA can only be realized when these technologies are adequately integrated into the organization's operations. Finally, Hypothesis 3 proposes that Digitalization Technical Competency moderates the IA-SCR relationship. The degree of digital and technical proficiency within an organization determines its ability to successfully implement IA solutions. Firms with higher digitalization technical competency are more likely to leverage IA technologies effectively, thus maximizing their impact on SCR (Ghobkhloo & Ng, 2019; Tang *et al.*, 2021). Conversely, organizations with limited technical capabilities may struggle with IA implementation, limiting its contribution to supply chain resilience (Hernandez-Perlines et al., 2025); Chong *et al.*, 2021). The model suggests that these three factors; IA, Integrability, and Digitalization Technical Competency, collectively influence SCR, with Integrability serving as a mediator and Digitalization Technical Competency acting as a moderator. The Conceptual model of study is provided in Fig. 1.

Research methodology

This study adopts a quantitative, mixed-method research design to examine how Intelligent Automation (IA) influences Supply Chain Resilience (SCR), with particular emphasis on the mediating roles of Integrability and Visibility. To capture both linear relationships and configurational patterns, the study integrates two complementary analytical techniques: Partial Least Squares Structural Equation Modeling (PLS-SEM) and fuzzy-set Qualitative Comparative Analysis (fsQCA). This dual approach allows for a more comprehensive understanding of the causal complexity underlying digital transformation and resilience in supply chains.

The survey instrument was developed using validated scales adapted from prior studies on intelligent automation, digital transformation, and supply chain resilience (Coombs et al., 2020; Lacity & Willcocks, 2021; Pettit et al., 2010; Mubarik et al., 2021). To ensure clarity and contextual appropriateness, the questionnaire underwent expert review by three academics and two practitioners, followed by a pre-test with 20 manufacturing managers. Based on their feedback, minor adjustments were made to wording and item sequencing. Because the survey was conducted in Lithuania, the instrument was translated from English to Lithuanian and back translated by two independent bilingual experts following Brislin (1980) procedure, ensuring linguistic accuracy and conceptual equivalence across both versions.

The empirical data were collected through a structured survey targeting supply chain, operations, and IT managers in manufacturing

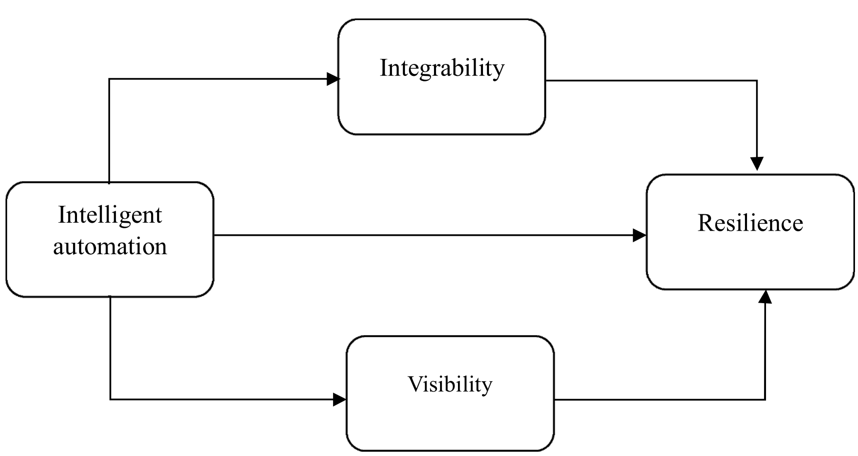

Fig. 1. Conceptual model of the study.

firms across Lithuania. This sector was chosen due to its active engagement with digital technologies and its critical role in national and regional economic resilience. Using a convenience sampling strategy, the survey yielded 312 valid responses. Respondents were required to have sufficient knowledge of their firm's technological infrastructure, digital integration initiatives, and supply chain operations to ensure the reliability of the responses. The survey instrument was developed based on validated scales from prior literature, measuring constructs such as IA, Integrability, Visibility, and SCR. The measurement model was first assessed using PLS-SEM via SmartPLS 4, examining the reliability, validity, and structural relationships among variables. This technique was appropriate for the study's exploratory nature, moderate sample size, and the inclusion of multiple latent constructs.

To complement the variance-based findings, fsQCA was employed using fsQCA 4.1 software. All constructs were calibrated into fuzzy sets using the direct method. The use of fsQCA is appropriate because resilience & digital capability formation often emerge through complex, non-linear interactions rather than single-variable effects. According to studies in organizational capability research (e.g., Hernandez-Perlines et al., 2016), fsQCA enabled the identification of multiple, equifinal configurations of conditions that are sufficient for achieving high SCR. This configurational analysis added nuance by revealing how different combinations of IA, Integrability, and Visibility lead to resilience, particularly in resource-constrained or digitally heterogeneous environments. By integrating both methods, the study provides robust insights into not only whether IA improves SCR, but also under what combinations of conditions such improvements are most likely to occur. This methodological triangulation strengthens the internal validity and theoretical generalizability of the findings.

Results

Validity and reliability of construct

The first step in this assessment involved examining the outer loadings of each indicator on its respective latent construct. In general, outer loadings above 0.70 are considered acceptable as they indicate that the item shares substantial variance with its associated construct (Chin, 1998). In this study, all observed items demonstrated satisfactory loadings, with most exceeding the 0.74 threshold. For instance, items related to Visibility (e.g., Visibility1 = 0.916, Visibility2 = 0.870, Visibility3 = 0.874) showed exceptionally strong associations with their underlying construct, suggesting high indicator reliability. Similarly, Integration items (e.g., Integ.4 = 0.875) also loaded strongly on the construct. Although a few items, such as IND.AUT3 (0.724) and IA3 (0.743), slightly approached the lower acceptable limit, they still met the minimum requirement, supporting their inclusion in the model.

The second stage of evaluation focused on internal consistency reliability, assessed using Cronbach's alpha. This metric evaluates how well a group of items measures a single unidimensional latent construct. Cronbach's alpha values above 0.70 are considered indicative of good reliability (Hair *et al.*, 2019). The constructs in this study all met this benchmark, with Supply Chain Resilience and Intelligent Automation achieving the highest reliability (α = 0.913 and 0.911, respectively), followed by Integration (α = 0.876) and Visibility (α = 0.864). These high alpha values confirm that the scale items are consistently measuring their intended constructs and suggest low measurement error.

Complementing Cronbach's alpha, the study also reported composite reliability (rho_C) and Dijkstra Henseler's rho_A, both of which offer a more precise estimation of reliability in PLS-SEM (Dijkstra and Henseler, 2015). Composite reliability values greater than 0.70 are considered acceptable, with higher values indicating stronger reliability (Hair *et al.*, 2019). All constructs exceeded this threshold, with rho_C values ranging from 0.915 (Integration) to 0.933 (Supply Chain Resilience). Similarly, rho_A values confirmed these findings, further reinforcing the reliability of the constructs used in the study. These results collectively indicate that the measurement scales possess high internal consistency and are well suited for evaluating the structural model.

Finally, convergent validity was evaluated using the Average Variance Extracted (AVE). AVE measures the level of variance captured by a construct relative to the level due to measurement error, with values above 0.50 indicating acceptable convergent validity (Fornell & Larcker, 1981). The AVE values for all constructs exceeded this threshold, ranging from 0.584 for Intelligent Automation to 0.787 for Visibility shown in Table 1, suggests that a substantial portion of the variance in the observed indicators is accounted for by their respective latent constructs, affirming the convergent validity of the measurement model. The results are provided in Table 1.

In evaluating the quality of the measurement model, it is critical to assess multicollinearity among the observed indicators. This was accomplished through the calculation of the Variance Inflation Factor (VIF) values, which quantify how much the variance of an estimated regression coefficient is increased due to collinearity. According to Hair *et al.* (2019), VIF values below 5.0 are generally considered acceptable, while values below 3.3 are preferable for more conservative analyses. Excessively high VIF values (typically above 5 or 10) may indicate problematic multicollinearity, which can distort estimations and inflate standard errors. the VIF analysis confirms that multicollinearity among the measurement indicators is within acceptable limits, thereby supporting the robustness of the outer measurement model. The absence of multicollinearity issues strengthens the validity of the indicator weights and ensures that the structural path coefficients in subsequent analysis are not biased by overlapping predictor effects.

Discriminant validity of constructs

To further assess the validity of the measurement model, discriminant validity was evaluated using the Heterotrait-Monotrait Ratio of Correlations (HTMT). This approach, as proposed by Henseler et al. (2015), is considered more reliable than the traditional Fornell-Larcker criterion and cross-loadings, particularly in identifying problems of discriminant validity in variance-based structural models.

Before presenting the technical results, it is important to note in plain terms what the discriminant validity tests confirm. Discriminant validity ensures that the study's main constructs Intelligent Automation (IA), Integrability, Visibility, and Supply Chain Resilience (SCR) are statistically distinct and not overlapping in measurement. In other words, each construct captures a unique aspect of the digital resilience framework, which strengthens the reliability of subsequent path analyses. Both the HTMT ratio and the Fornell–Larcker criterion confirm that these constructs are clearly differentiated, indicating that the model measures conceptually distinct but related dimensions of supply chain digital capability.

HTMT values below 0.90 are generally regarded as acceptable, indicating that constructs are sufficiently distinct from one another. In the current study, all HTMT values fall below the conservative threshold of 0.90, supporting the discriminant validity of the constructs. The HTMT value between Intelligent Automation (IA) and Supply Chain Resilience (SCR) was 0.845, suggesting that although these constructs are closely related as anticipated by the theoretical framework, they remain empirically distinguishable. Similarly, the HTMT value between IA and Visibility was 0.843, which also supports the notion that while IA enhances visibility in supply chains, the two are conceptually and statistically distinct constructs. As shown in Table 2, all HTMT values fall below the conservative threshold of 0.85, providing strong support for discriminant validity.

In addition to the HTMT analysis, discriminant validity of the measurement model was also evaluated using the Fornell–Larcker criterion, a traditional yet widely accepted approach in structural equation modeling (Fornell & Larcker, 1981). This method requires that the square root of the Average Variance Extracted (AVE) for each construct should be greater than its correlations with any other construct in the

Table 1
Validity and reliability of constructs.

Variables	Outer loadings	Cronbach's alpha	Composite reliability (rho_a)	Composite reliability (rho_c)	Average variance extracted (AVE)
Intelligent Automation					
IA.RES1	0.810	0.911	0.912	0.926	0.584
IA.RES2	0.804				
IA.RES3	0.760				
IA1	0.758				
IA2	0.765				
IA3	0.743				
IND.AUT1	0.765				
IND.AUT2	0.743				
IND.AUT3	0.724				
Integration					
Integ.1	0.821	0.876	0.880	0.915	0.730
Integ.2	0.854				
Integ.3	0.866				
Integ.4	0.875				
Visibility					
Visibility1	0.916	0.864	0.866	0.917	0.787
Visibility2	0.870				
Visibility3	0.874				
Supply chain resilience					
SCCONF1	0.835	0.913	0.915	0.933	0.697
SCCONF2	0.852				
SCR R1	0.795				
SCR R2	0.813				
SCRES 1	0.850				
SCRES2	0.865				

Table 2
Discriminant validity of constructs (HTMT values).

	Intelligent automation (IA)	SC Resilience (SCR)	Visibility (VIS)	Integration (Integ.)
IA				
SCR (SCR)	0.845			
Visibility (VIS)	0.843	0.736		
Integration (Integ.)	0.830	0.866	0.789	

model. The square root of AVE appears on the diagonal of the Fornell-Larcker matrix, while the off-diagonal values represent the inter-construct correlations. The results presented in Table 3 demonstrate that discriminant validity is established for all constructs. Specifically, the square root of AVE for Intelligent Automation (IA) is 0.764, which is higher than its correlations with Supply Chain Resilience (0.773), Visibility (0.748), and Integration (0.746). While the correlation between IA and SCR is relatively high, it does not exceed the square root of AVE for either construct, satisfying the criterion. Similarly, the square root of AVE for Supply Chain Resilience (SCR) is 0.835, which is greater than its correlations with IA (0.773), Visibility (0.654), and Integration (0.779). The Visibility construct has a notably high AVE (square root = 0.887), which exceeds its highest correlation value of 0.748 with IA shown in Table 3, advocates that the construct is strongly defined by its own indicators and not unduly influenced by other latent variables. Finally, the Integration construct, with a square root of AVE of 0.854, also meets the criterion. Its highest correlation is with SCR (0.779), yet this remains below the square root of its AVE, confirming discriminant validity.

Table 3
Fornell Larcker criterion.

	Intelligent automation (IA)	SC RESILIENCE (SCR)	Visibility (VIS)	Integration (Integ.)
IA	0.764			
SCR (SCR)	0.773	0.835		
Visibility (VIS)	0.748	0.654	0.887	
Integration (Integ.)	0.746	0.779	0.689	0.854

Although the path from IA to Visibility is strong and significant, the subsequent effect of Visibility on Supply Chain Resilience is not statistically supported. This finding suggests that while Intelligent Automation improves transparency and monitoring across the supply chain, visibility alone is insufficient to enhance resilience unless it is supported by deeper process integration and decision autonomy. This result indicates that transparency must be operationalized through integrated, action-oriented systems to produce measurable resilience benefits, foreshadowing the configurational findings discussed later in the paper.

Results of the structural model

The structural model was evaluated to test the hypothesized relationships between Intelligent Automation (IA), Integrability, Visibility, and Supply Chain Resilience (SCR). The path coefficients (β), t-statistics, and p-values were examined to assess the strength and significance of relationships, while R^2 values provided insights into the model's explanatory power.

The direct effect of Intelligent Automation on Supply Chain Resilience (H1) is statistically significant ($\beta = 0.412$, $t = 6.245$, $p < 0.001$) presented in Table 4, indicates that greater adoption of IA positively influences the ability of supply chains to absorb and recover from disruptions. The result supports prior literature suggesting that

Table 4
Structural model assessment.

	Paths	Beta	T statistics	P values	Decision
H1	IA →SCR	0.412	6.245	0.000	Accepted
H2	IA → integ →SCR	0.331	6.911	0.000	Accepted
	IA →Integ.	0.746	24.606	0.000	
	Integ. →SCR	0.443	6.825	0.000	
H3	IA→ Visibility → SCR	0.031	0.685	0.493	Rejected
	IA → Visibility	0.748	26.251	0.000	
	Visibility → SCR	0.041	0.689	0.491	

R-Square/Adjusted R-Square values: SCR=0.691/0.688; Vis.=0.560/0.559; Integ.=0.557/0.555

Abbreviations: IA- Intelligent Automation; SCR-Supply Chain Resilience; Integ.-Integratability; Vis.-Visibility technologies like AI, RPA, and ML enhance real-time responsiveness and decision-making, thus improving resilience (Coombs *et al.*, 2020; Lacity & Willcocks, 2021).

The mediating role of Integrability in the relationship between IA and SCR (H2) is also supported (β = 0.331, t = 6.911, p < 0.001). The specific paths, H2a (IA → Integrability) and H2b (Integrability → SCR), are both highly significant (β = 0.746, t = 24.606 and β = 0.443, t = 6.825, respectively) shown in Table 4. This suggests that IA enhances integrability within the supply chain, which in turn contributes significantly to greater resilience. These findings are aligned with previous studies asserting that seamless integration between digital technologies and legacy systems is critical for maximizing the benefits of intelligent automation (Jha *et al.*, 2021; Ghobakhloo & Ching, 2019).

Hypothesis H3, which proposed that Visibility mediates the relationship between IA and SCR, is not supported (β = 0.031, t = 0.685, p = 0.493). Although the direct path from IA to Visibility (H3a) is significant (β = 0.748, t = 26.251, p < 0.001), the path from Visibility to SCR (H3b) is not significant (β = 0.041, t = 0.689, p = 0.491) provided in Table 4, suggests that while IA enhances visibility, increased visibility alone does not translate into a measurable improvement in supply chain resilience in this context. This may reflect the fact that visibility is a necessary but not sufficient condition for resilience it must be complemented by other dynamic capabilities like integration, responsiveness, or decision autonomy (Mubarik *et al.*, 2021).

The R^2 value for Supply Chain Resilience is 0.691, indicating that approximately 69.1 % of the variance in SCR is explained by IA, Integrability, and Visibility combined. Similarly, the R^2 values for Visibility (0.560) and Integrability (0.557) show that IA explains a moderate to substantial portion of variance in these mediators. These values shown in Table 4, suggest that the model has strong explanatory power, consistent with guidelines by Hair *et al.* (2019) for PLS-SEM. Detailed results of the structural model assessment are also provided in Table 4.

Beyond statistical significance, the strength of the path coefficient (β = 0.412, $p < 0.001$) from Intelligent Automation (IA) to Supply Chain Resilience (SCR) indicates a substantively large effect, suggesting that firms with higher levels of IA adoption are considerably better equipped to anticipate and recover from disruptions. In practical terms, this means that implementing IA technologies such as AI-driven predictive analytics and robotic process automation enhances real-time decision-making, operational agility, and response speed. Similarly, the significant mediating effect of Integrability (β = 0.331, $p < 0.001$) underscores that resilience gains are most pronounced when IA is accompanied by seamless data and process integration, enabling synchronized actions across supply chain nodes. These findings collectively demonstrate that IA is not only statistically influential but also managerially consequential, shaping how digital capabilities are configured to achieve resilient supply chain performance.

Fuzzy-set qualitative comparative analysis (fsQCA) results

Analysis of necessary conditions

To complement the PLS-SEM findings and deepen the configurational understanding of the conditions under which Intelligent Automation (IA) contributes to Supply Chain Resilience (SCR), a fuzzy-set Qualitative Comparative Analysis (fsQCA) was conducted. This method allows for identifying combinations of causal conditions that are sufficient and/or necessary for the outcome, emphasizing equifinality as the notion that multiple pathways can lead to the same result.

Prior to the configurational analysis, all variables were calibrated into fuzzy sets using the direct method (Ragin, 2008). Calibration thresholds were determined using the empirical distribution of the data: the 95th percentile was set as the threshold for full membership (fuzzy score = 0.95), the 50th percentile as the crossover point (fuzzy score = 0.50), and the 5th percentile as the full non-membership threshold (fuzzy score = 0.05). These thresholds ensure that the fuzzy scores accurately represent the degree of set membership across cases and align with established practices in fsQCA applications within operations and digital transformation research (Wamba-Taguimdje et al., 2020; Belhadi et al., 2021). This calibration process was performed in fsQCA 4.1 software prior to generating the truth table and assessing necessary and sufficient conditions.

The analysis of necessary conditions as presented in Table 5 indicates that no single condition independently is universally necessary for high SCR. However, combinations of conditions exhibit high consistency and coverage values, suggesting their potential necessity in shaping resilience outcomes.

Most notably, the configuration IA + INTEG + VIS shows a consistency of 0.970 and coverage of 0.889, indicating that the simultaneous presence of intelligent automation, integrability, and visibility is nearly always observed when supply chain resilience is high. This supports the central thesis of this study that IA, when effectively integrated and accompanied by visibility mechanisms, significantly strengthens resilience capabilities. Interestingly, the configuration IA + INTEG + ∼VIS also yields a high consistency (0.949) and even greater coverage (0.910) provided in Table 5, underscoring the strong mediating role of integrability, as evidenced in the PLS-SEM results. This finding reinforces the insight that visibility, while beneficial, is not a necessary condition for resilience to manifest, particularly when intelligent automation and integration are robust. This nuance corroborates the earlier conclusion that visibility alone is insufficient and must be accompanied by decision-making agility or systemic integration to yield resilience outcomes.

Moreover, the configuration ∼IA + INTEG + VIS presents a high consistency of 0.959 and a substantial coverage of 0.891 shown in Table 5, suggest that even in the absence of advanced automation, strong integrability and visibility may still foster resilient supply chains. This pathway reflects scenarios in emerging economies where legacy systems, if well-integrated and made transparent, can offer resilience without full-scale adoption of intelligent automation highlighting a resource-constrained adaptation pathway. Conversely, the configuration IA + ∼INTEG + ∼VIS displays the lowest consistency (0.877) among the examined combinations yet shows the highest coverage (0.974) presented in Table 5, suggests that while this combination is common among observed cases, it is not consistently associated with high resilience. This reflects a technocentric fallacy where firms adopt IA tools without enabling integration or visibility mechanisms resulting in suboptimal resilience outcomes. It reiterates the earlier theoretical claim that automation alone is not a panacea, and its strategic value depends critically on contextual integration and supporting systems.

Collectively, these fsQCA detailed findings are aligned with the TOE framework and support the assertion that supply chain resilience emerges from synergistic interactions, rather than from isolated technologies or capabilities. They offer empirical nuance to the SEM results by showing that multiple causal recipes both automation-driven and integration-led can yield resilient supply chains, particularly within the constraints and configurations typical of emerging economies.

Discussion

The findings of this study contribute to the broader discourse on digital transformation and supply chain resilience through four interrelated insights. First, the results highlight the pivotal role of

Table 5
Analysis of necessary conditions.

Condition	Consistency	Coverage
IA + INTEG + VIS	0.970411	0.889348
IA + INTEG + ∼VIS	0.949683	0.909886
IA + ∼INTEG + VIS	0.934691	0.935413
∼IA + INTEG + VIS	0.959454	0.890654
IA + ∼INTEG + ∼VIS	0.876885	0.974389
∼IA + INTEG + ∼VIS	0.889818	0.911554
∼IA + ∼INTEG + VIS	0.888632	0.940931

Integrability as the dynamic mechanism that translates Intelligent Automation (IA) into tangible resilience outcomes underscoring that technological sophistication alone is insufficient without systemic integration across organizational layers. Second, the study provides a nuanced understanding of Visibility, revealing that transparency enhances monitoring but does not independently guarantee resilience unless coupled with decision autonomy and integrated coordination. Third, by identifying multiple equifinal pathways through fsQCA, the analysis demonstrates that emerging economies can achieve resilience through context-specific configurations, even under resource constraints illustrating the adaptability of digital transformation strategies. Fourth, the results expose technocentric risks, showing that automation implemented without integrative and human-centered design may lead to fragmented systems and suboptimal outcomes. Collectively, these contributions reinforce the TOE framework and systems theory perspective, showing that resilience arises from the alignment and interaction of technological, organizational, and environmental subsystems rather than from isolated digital interventions.

This study offers compelling evidence that Intelligent Automation (IA) plays a significant role in enhancing Supply Chain Resilience (SCR). The results of the structural model affirm that IA has a strong and positive direct effect on SCR, validating its strategic value in helping firms anticipate, respond to, and recover from disruptions. These findings align with existing literature (e.g., Riad et al., 2025; Ghadge et al., 2022), which underscores the role of IA technologies such as artificial intelligence, machine learning, and robotic process automation in strengthening supply chain agility, risk detection, and decision-making. As noted by Ivanov and Dolgui (2020), IA enables real-time adjustments to disruptions through dynamic resource reallocation and operational reconfiguration. However, as other scholars have emphasized (e.g., Sanders et al., 2023), the realization of IA's benefits is contingent upon a firm's digital readiness, organizational culture, and technical capacity.

A key contribution of this study is the identification of Integrability as a crucial mediating mechanism between IA and SCR. The findings demonstrate that IA improves resilience more effectively when it is seamlessly integrated into existing IT infrastructure and business processes. Integrability enables real-time data exchange, process coordination, and system interoperability, all of which are essential for a cohesive and responsive supply chain. This finding supports the argument that digital transformation outcomes are not solely determined by technological sophistication but by the ability to embed and harmonize these technologies within operational routines (Belhadi et al., 2021; Wamba et al., 2020). The development of a scalable and modular digital infrastructure thus emerges as a prerequisite for leveraging the full value of IA in resilience-building.

The robustness of this insight is further corroborated by the fsQCA analysis, which provides a configurational lens on the conditions leading to high SCR. The configuration *IA * INTEG * VIS* exhibited perfect consistency, confirming that when IA is implemented alongside strong integrability and visibility, it constitutes a highly effective pathway to resilience. However, the fsQCA also revealed that resilience can be achieved even in the absence of one component particularly visibility provided the other conditions are sufficiently strong. For instance, *IA * INTEG* ~VIS* also demonstrated high consistency and coverage, reinforcing the PLS-SEM result that visibility, while enhanced by IA, does not significantly mediate its effect on SCR. This nuanced understanding challenges the assumption that visibility is inherently transformative. While IA significantly improves supply chain visibility through enhanced monitoring, tracking, and real-time data flow the lack of a significant path from visibility to SCR suggests that transparency alone is insufficient. As Ivanov (2020) and Wamba & Queiroz (2020) argue, visibility must be supported by analytical capabilities and decision autonomy to translate into actionable resilience. The fsQCA results further illustrate this point: configurations lacking integration or agility, even with strong visibility, do not consistently result in high resilience.

Moreover, alternative pathways identified through fsQCA (e.g., *~IA * INTEG * VIS*) suggest that in resource-constrained contexts, firms may still achieve resilience by emphasizing integrability and visibility, even without extensive IA implementation. This is especially pertinent for emerging economies like Lithuania, where limited digital maturity or financial constraints may inhibit full-scale automation. Such findings highlight the relevance of context-sensitive strategies, where resilience can be configured through alternative combinations of technological and organizational enablers. Conversely, the configuration *IA * ~INTEG * ~VIS*, which showed high coverage but lower consistency, points to the risk of adopting IA in isolation. This reflects a technocentric fallacy assuming that digital tools alone can deliver resilience without supportive integration and visibility mechanisms. These firms may invest in advanced technologies but fail to achieve resilience gains due to fragmented systems and poor coordination.

Taken together, the combined results from PLS-SEM and fsQCA provide a comprehensive understanding of how resilience emerges from the interaction of technology, integration capability, and visibility. Rather than a linear cause-effect relationship, SCR is the outcome of complex, mutually reinforcing configurations an insight consistent with both the TOE framework and systems theory. This integrated perspective contributes to a more nuanced and practice-oriented understanding of digital supply chain transformation, particularly in the context of emerging markets.

Beyond the technological and configurational insights, the findings also hold strong implications for training and innovation management within supply chains. The integration of Intelligent Automation (IA) requires not only technical investment but also the development of human capital capable of interacting with and enhancing automated systems. As the results indicate, the mediating role of integrability underscores that the effectiveness of IA depends on workforce proficiency, adaptive learning, and innovation-oriented managerial practices. Firms must therefore cultivate digital fluency and cross-functional collaboration through continuous training programs that enable employees to interpret data, manage automated workflows, and co-create process innovations. Such initiatives transform automation from a purely efficiency-driven mechanism into a driver of organizational learning and innovation renewal (Hernandez-Perlines et al., 2025; Coombs et al., 2020; Lacity & Willcocks, 2021). In line with recent perspectives on learning-based resilience (Belhadi et al., 2021; Ivanov & Dolgui, 2020), the development of dynamic training and knowledge-sharing ecosystems enhances both the technological utilization of IA and the organization's adaptive capacity. This human-centric orientation reinforces that supply chain resilience emerges from the synergy between intelligent technologies and intelligent people who can leverage them creatively to innovate and respond to disruption.

Beyond its methodological and empirical contributions, this study offers theoretical originality by extending the absorptive capacity-based view (Zahra & George, 2002; Todorova & Durisin, 2007) into the domain of intelligent automation–driven resilience. Traditional absorptive capacity theory emphasizes an organization's ability to acquire, assimilate, transform, and exploit knowledge; our findings advance this logic by demonstrating how digital absorptive capacity embodied in integrability and visibility mediates the translation of intelligent automation into resilient performance outcomes. In doing so, the study reconceptualizes integrability not merely as a technical interface but as a dynamic learning capability that enables the internalization and reconfiguration of knowledge flows across digital systems and organizational routines. This perspective shifts the discourse from a descriptive account of technological adoption to an integrative capability-based understanding of how firms sense, adapt, and respond to disruptions through intelligent automation. By fusing the TOE framework with the absorptive capacity lens, the study contributes to theory building on digital transformation by illustrating that resilience emerges when technological, cognitive, and organizational learning mechanisms are jointly activated (Wamba et al., 2020; Belhadi et al., 2021; Ivanov & Dolgui, 2020).

Implications of study

Practical

The findings of this study offer several important implications for supply chain professionals seeking to enhance organizational resilience in the face of growing uncertainty and disruption. First, the confirmed direct effect of Intelligent Automation (IA) on Supply Chain Resilience (SCR) highlights the need for firms to invest strategically in advanced technologies such as artificial intelligence, robotic process automation (RPA), and machine learning. These technologies enable proactive disruption management, real-time analytics, and dynamic process reconfiguration. However, the results from both PLS-SEM and fsQCA underscore that IA alone is insufficient its effectiveness depends on how well it is embedded within the firm's operational and digital infrastructure.

The strong mediating role of Integrability calls for deliberate integration strategies. Organizations must go beyond deploying isolated digital tools and instead pursue seamless interoperability between legacy systems and emerging technologies. This includes investing in modular architectures, integration middleware, and API-driven platforms that support cross-functional collaboration. The fsQCA analysis reinforces this point by demonstrating that resilience is not achieved through technology adoption alone, but through the right configuration of IA, integrability, and where applicable visibility.

Second, the results challenge the common perception that visibility is inherently sufficient for resilience. While IA significantly improves visibility, neither SEM nor fsQCA support its role as a standalone enabler of SCR. This suggests that visibility must be paired with analytical capabilities, decision autonomy, and system integration to generate meaningful resilience outcomes. Practitioners should thus be cautious in overinvesting in visibility dashboards without ensuring that the data flows into actionable and integrated decision-making systems.

Third, fsQCA reveals that alternative configurations of resilience are viable, especially in resource-constrained environments. For example, firms with limited automation but strong integration and visibility can still build resilient supply chains. This highlights the importance of context-sensitive strategies, allowing organizations in emerging economies to adapt digital transformation pathways based on their maturity, resources, and ecosystem readiness.

Finally, the identification of configurations such as IA + ~INTEG + ~VIS, which yield inconsistent resilience outcomes, serves as a cautionary note. Firms must avoid technocentric implementation investing in automation without the enabling infrastructure or organizational alignment to support its effective use. For managers, this means adopting a systemic view of resilience, ensuring that technology is tightly coupled with processes, people, and structural integration mechanisms.

Theoretical

From a theoretical standpoint, this study contributes to the digital supply chain and operations management literature by expanding the Technology–Organization–Environment (TOE) framework. It operationalizes Integrability and Visibility as mediating constructs and demonstrates that digital transformation outcomes are shaped by configurational interdependencies rather than linear relationships. The fsQCA findings complement the PLS-SEM results by offering equifinal pathways to resilience indicating that multiple condition sets (e.g., IA + INTEG, or INTEG + VIS) can lead to similar resilience outcomes. This configurational logic reinforces the systems theory perspective, which emphasizes that organizational performance emerges from the alignment of subsystems technological, structural, and cognitive. The finding that IA is not uniformly effective unless paired with integrability or visibility challenges the traditional assumption of technological determinism and encourages a more nuanced understanding of digital capability bundles.

Moreover, the fsQCA evidence questioning the sufficiency of visibility challenges existing models that regard transparency as inherently valuable. It supports emerging theoretical critiques (e.g., Ivanov & Dolgui, 2020) that argue for a more contextual and contingent view of visibility one that depends on interpretive capacity, responsiveness, and organizational agility. By demonstrating that resilience can be configured through different combinations of capabilities, especially in emerging economy contexts, the study makes a situated theoretical contribution. It highlights that digital transformation and resilience-building are not one-size-fits-all processes but are influenced by local constraints, legacy systems, and strategic priorities. Finally, this study adopts a technocentric lens, emphasizing the functionality and operational benefits of IA. While this approach aligns with the study's objectives, it does not fully account for the socio-technical challenges of automation, including workforce resistance, digital skill gaps, and ethical concerns. Future research using qualitative or mixed methods could explore these dimensions in depth, thereby offering a more comprehensive understanding of the human factors and institutional barriers affecting digital resilience.

Conclusions

This study demonstrates that Intelligent Automation (IA) contributes to Supply Chain Resilience (SCR) not merely through technological adoption but through its integration within organizational systems and adaptive processes. Grounded in the Technology-Organization-Environment (TOE) framework, the findings reveal that resilience emerges from the alignment of technological and organizational capabilities, rather than from automation alone. The study provides evidence that Integrability acts as the pivotal mechanism translating IA into resilience, emphasizing that technologies create value only when embedded in interoperable systems that enable coordinated decision-making and responsiveness.

A nuanced view of Visibility also emerged: while IA enhances transparency and monitoring, visibility by itself does not guarantee resilience unless coupled with integrability and agility. The fsQCA analysis further underscores that resilience can result from multiple, context-specific configurations of digital capabilities, offering valuable insight for firms in emerging economies, where resource constraints and digital maturity levels vary.

Overall, the research advances a systemic understanding of digital resilience, showing that strong supply chains are not built solely on the presence of intelligent technologies but on their strategic orchestration within socio-technical systems. For managers, the implication is clear: achieving resilience requires not just digital investment but intentional alignment of technology, people, and processes to create adaptive, learning-oriented supply chain networks.

Limitations and future research directions

While this study offers valuable insights into the relationship between Intelligent Automation (IA) and Supply Chain Resilience (SCR), several limitations should be acknowledged. Primarily, the research is contextually limited to manufacturing firms in Lithuania, a small and emerging European economy. The findings may not be fully generalizable to firms in more developed economies or across other sectors, where digital maturity, infrastructure, and regulatory environments differ significantly. Moreover, future research could adopt comparative multi-country studies to explore how national and institutional contexts shape the impact of IA on SCR. Second, the study employed a cross-sectional design, capturing a snapshot of firms' current capabilities and resilience levels. This limits the ability to infer causality or track changes over time. Longitudinal studies could provide a more dynamic understanding of how IA, Integrability, and Visibility evolve and influence resilience during different stages of disruption. Finally, while this study focused on Integrability and Visibility as mediators, other factors such as digital trust, agility, learning capability, or collaborative governance may also influence the IA-SCR relationship. Future research should incorporate such constructs to develop a more holistic framework. Additionally, qualitative or mixed-methods approaches could uncover deeper insights into socio-technical and human dimensions of digital transformation, including workforce readiness, resistance, and ethical concerns surrounding automation.

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Mobashar Mubarik: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Saule Maciukaite-Zviniene:** Writing – review & editing, Writing – original draft, Validation, Resources, Methodology, Investigation, Funding acquisition, Conceptualization.

Declaration of competing interest

Not applicable

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