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From Autonomous Intelligence to Adaptive Resilience: How Agentic AI and Digital Twin Capabilities Shape Supply Chain Resilience Through Sensemaking and Human-AI Collaboration

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ABSTRACT

This study examines how Agentic AI Capability and Digital Twin Capability enhance Supply Chain Resilience, considering the mediating role of Supply Chain Sensemaking Capability and the moderating role of Human-AI Collaboration. Using a quantitative cross-sectional design, data were collected from 305 supply chain and related professionals and analyzed through Partial Least Squares Structural Equation Modeling (PLS-SEM). The findings reveal that Agentic AI Capability and Digital Twin Capability significantly improve both supply chain sensemaking and resilience. Supply Chain Sensemaking Capability also significantly strengthens Supply Chain Resilience and partially mediates the effects of both technological capabilities. Furthermore, Human-AI Collaboration significantly strengthens the relationship between sensemaking capability and supply chain resilience. The model demonstrates substantial explanatory power, accounting for 64.3% of the variance in Supply Chain Sensemaking Capability and 67.8% in Supply Chain Resilience. The study highlights that resilient supply chains depend not only on advanced digital technologies but also on effective organizational interpretation and collaboration between human decision-makers and AI systems.

Introduction

Contemporary supply chains operate in an environment characterized by increasing uncertainty, technological disruption, geopolitical tensions, demand volatility, supplier failures, transportation interruptions, climate-related events, cybersecurity threats, and rapidly changing customer expectations. These conditions have made conventional approaches to supply chain planning and risk management increasingly insufficient. Organizations are therefore shifting from reactive supply chain management toward digitally enabled systems capable of identifying emerging risks, interpreting complex information, anticipating disruptions, and supporting rapid and adaptive decision-making. Consequently, supply chain resilience has become a critical strategic capability for organizations seeking to maintain continuity and competitiveness in turbulent environments (Stadtfeld & Gruchmann, 2024; Siddiqui et al., 2025).

Digital transformation has played an important role in this transition. Technologies such as artificial intelligence (AI), machine learning, predictive analytics, Internet of Things (IoT), advanced data analytics, and digital twins are increasingly incorporated into supply chain activities. These technologies improve the capacity of organizations to collect and process information, monitor supply networks, anticipate risks, coordinate activities, and make data-driven decisions. Siddiqui et al. (2025), for instance, emphasize the complementary importance of digitalization and resilience in improving supply chain performance. Similarly, Smyth et al. (2024) identify AI and prescriptive analytics as important technological resources for strengthening supply chain resilience through enhanced information processing and decision support.

Among recent technological developments, Agentic Artificial Intelligence (Agentic AI) represents an important advancement beyond conventional AI applications. Traditional AI systems typically perform predefined analytical tasks and provide recommendations that require human initiation or interpretation. Agentic AI systems, in contrast, are designed to demonstrate greater autonomy by perceiving environmental conditions, reasoning about problems, establishing or following goals, planning sequences of activities, interacting with other agents, and initiating appropriate actions. In supply chain environments, these capabilities could enable AI agents to continuously monitor suppliers, inventory levels, logistics operations, market conditions, and emerging disruptions while supporting coordinated and timely decisions. Emerging research on autonomous multi-agent systems illustrates the potential of agentic AI for supply chain coordination and consensus-based decision-making (Jannelli et al., 2025).

Another rapidly developing technology is Digital Twin Intelligence (DTI). Digital twins create virtual representations of physical supply chain systems and continuously synchronize these representations with operational information. When combined with AI, analytics, simulation, and real-time data, digital twins can evolve from static representations into intelligent decision-support environments. Such systems allow managers to observe current supply chain conditions, identify interdependencies, simulate potential disruptions, evaluate alternative responses, and anticipate the consequences of decisions before implementing them. Recent literature indicates that digital twins have considerable potential to improve supply chain efficiency, visibility, decision-making, and resilience (Nakache et al., 2025; Liu et al., 2026).

However, possessing advanced technology does not necessarily guarantee resilience. Organizations must be capable of interpreting the information produced by these systems and converting technological intelligence into meaningful organizational responses. This requirement highlights the importance of Supply Chain Sensemaking Capability (SCSC). Sensemaking concerns the process through which organizational actors interpret ambiguous information, construct meaning from uncertain situations, develop shared understandings, and determine appropriate courses of action. Kaneberg et al. (2026) demonstrate that supply chain resilience is closely connected with interpretive processes through which organizations understand disruption experiences and mobilize appropriate capabilities. Similarly, Rashid and Rasheed (2026) highlight organizational sensemaking as an important mechanism in the relationship between AI-powered risk mitigation and supply chain resilience.

The present study further extends conventional resilience thinking by emphasizing Supply Chain Cognitive Resilience (SCCR). While conventional supply chain resilience frequently emphasizes operational recovery, redundancy, flexibility, and continuity, cognitive resilience focuses on an organization's capacity to remain cognitively prepared under uncertainty. It involves recognizing weak signals, interpreting disruptions, questioning existing assumptions, anticipating consequences, updating understanding as conditions evolve, and making adaptive decisions. In highly digitalized supply chains, the ability to think, interpret, and adapt may become as important as physical resources and operational buffers.

Moreover, as AI assumes increasingly sophisticated roles in supply chain decision-making, resilience is unlikely to depend solely on autonomous technological systems. Human-AI Collaboration (HAIC) may determine whether machine-generated intelligence is effectively combined with managerial experience, contextual knowledge, intuition, ethical judgment, and strategic understanding. Effective human-AI collaboration can allow organizations to combine the computational strengths of AI with the contextual and experiential strengths of human decision-makers. Therefore, this study proposes that HAIC strengthens the effect of supply chain sensemaking capability on supply chain cognitive resilience.

Against this background, the present study develops an integrated framework examining Agentic AI Capability (AAIC) and Digital Twin Intelligence (DTI) as antecedents of Supply Chain Cognitive Resilience (SCCR). It further investigates Supply Chain Sensemaking Capability (SCSC) as the mechanism through which these advanced technological capabilities are converted into cognitive resilience and examines Human-AI Collaboration (HAIC) as a boundary condition strengthening the SCSC–SCCR relationship. By integrating emerging AI capabilities, digital twin intelligence, organizational sensemaking, resilience, and human-AI collaboration within one framework, the study seeks to provide a contemporary explanation of how organizations can develop cognitively resilient supply chains in increasingly complex digital environments.

Background of the Study

Global supply chains have undergone considerable transformation during the past several years. Traditionally, supply chain management focused heavily on efficiency, cost reduction, inventory optimization, lean operations, and predictable supplier relationships. However, recent global disruptions have exposed the limitations of supply chains designed primarily around efficiency. Pandemic-related interruptions, geopolitical conflicts, trade restrictions, natural disasters, cyberattacks, logistics bottlenecks, raw-material shortages, and rapid demand changes have demonstrated that organizations must develop capabilities that allow them not only to operate efficiently but also to anticipate, absorb, interpret, and adapt to unexpected changes. As a result, resilience has moved from being an operational consideration to becoming a strategic supply chain priority (Stadtfeld & Gruchmann, 2024).

At the same time, the digitalization of supply chains has accelerated. Organizations increasingly rely on AI, analytics, cloud platforms, IoT technologies, automation, and digitally integrated information systems to manage complex networks of suppliers, manufacturers, distributors, and customers. Siddiqui et al. (2025) demonstrate the relevance of combining resilience and digitalization in explaining contemporary supply chain performance. Their findings reinforce the view that organizations operating in uncertain environments increasingly require digital capabilities alongside conventional supply chain resources.

AI represents one of the most influential technologies within this transformation. AI-supported systems can process large quantities of supply chain data, identify patterns, generate forecasts, detect anomalies, optimize inventories, predict equipment failures, identify supplier risks, and support logistics decisions. Smyth et al. (2024) emphasize the growing role of AI and prescriptive analytics in supporting supply chain resilience. Lin and Zhang (2025) similarly provide evidence connecting enterprise AI development with stronger supply chain resilience, including through improvements in information transparency.

The emerging development of agentic AI extends these capabilities further. Rather than limiting AI to isolated analytical functions, agentic systems potentially allow autonomous or semi-autonomous AI agents to interact with supply chain environments and perform multi-step tasks. For example, an agentic AI system could continuously observe supplier performance, identify an emerging delay, evaluate alternative suppliers, estimate downstream consequences, communicate with other digital agents, and recommend or initiate corrective actions. Jannelli et al. (2025) demonstrate the emerging application of agentic large language models to multi-agent supply chain decision-making and consensus-seeking. Such developments indicate that AI is gradually evolving from a decision-support technology toward an active participant in supply chain coordination.

Parallel to AI development, digital twin technology has attracted increasing attention in supply chain research. Digital twins create virtual counterparts of physical systems and allow organizations to integrate real-time operational data with simulation and analytical capabilities. Nakache et al. (2025) identify substantial potential for digital twins to improve supply chain efficiency and resilience, while Liu et al. (2026) emphasize their relevance across different stages of disruption management. By simulating alternative conditions, organizations can examine how supplier failure, transportation interruption, demand surges, capacity shortages, or other disturbances could propagate throughout the supply network before deciding how to respond.

However, technology generates value only when organizations are capable of interpreting and applying the information produced. This is particularly important under disruption because available information is frequently incomplete, contradictory, or ambiguous. Supply chain managers must determine which signals are important, what those signals mean, how a disruption may evolve, and what action should be taken. Supply chain sensemaking capability therefore becomes essential for converting data and technological intelligence into meaningful interpretations.

Kaneberg et al. (2026) show that resilience involves interpretive processes through which organizations frame disruptive events, reassess their resources, and mobilize appropriate capabilities. This suggests that digital technologies may provide signals and analytical insights, while sensemaking enables organizations to transform those insights into a coherent understanding of the situation. Consequently, sensemaking may represent a critical missing mechanism connecting emerging technologies with supply chain resilience.

Furthermore, resilience in highly digital environments increasingly involves a cognitive dimension. Organizations must be capable not merely of recovering physically from disruptions but also of recognizing changing conditions, challenging existing assumptions, learning rapidly, maintaining situational awareness, and adapting decision logic. The present study therefore introduces supply chain cognitive resilience as an outcome reflecting the cognitive and interpretive capacity of the organization to function adaptively under uncertainty.

The human dimension remains equally important. Ahmed et al. (2025), although studying AI-powered HRM, demonstrate that technological adoption generates stronger organizational outcomes through human and organizational mechanisms such as learning and engagement. Similarly, Ahmed et al. (2025) emphasize the importance of leadership and human-oriented organizational mechanisms in generating sustainability-related outcomes. These findings support a broader organizational principle that advanced technologies should not be considered independently from the human capabilities through which they are interpreted and implemented.

Accordingly, Human-AI Collaboration becomes particularly important. AI may provide computational speed, continuous monitoring, pattern recognition, and scenario evaluation, while humans provide experience, contextual understanding, intuition, ethical judgment, creativity, and strategic reasoning. Combining these complementary capabilities may enable organizations to translate supply chain sensemaking more effectively into cognitive resilience.

Problem Statement

Despite extensive investment in digital supply chain technologies, organizations continue to experience substantial difficulties in anticipating and responding effectively to disruptions. The availability of large quantities of real-time data and advanced analytical tools does not automatically ensure that supply chain managers can understand emerging threats or make appropriate decisions. Supply chain failures may occur not only because information is unavailable but because organizations fail to recognize important signals, interpret them correctly, develop shared understanding, or translate technological insights into coordinated responses.

Existing supply chain research has established the importance of digitalization, artificial intelligence, analytics, and digital twins for improving visibility, decision-making, efficiency, and resilience (Smyth et al., 2024; Siddiqui et al., 2025; Nakache et al., 2025; Lin & Zhang, 2025). Nevertheless, much of this literature considers digital technologies as tools that directly improve supply chain outcomes. Such an approach may overlook the organizational cognitive processes required to transform technologically generated information into resilient decisions.

This limitation becomes more significant with the emergence of agentic AI. Agentic AI systems differ from conventional analytical technologies because they may autonomously monitor environments, reason about problems, communicate with other systems, formulate plans, and initiate actions. Although these capabilities could fundamentally transform supply chain decision-making, empirical knowledge concerning how Agentic AI Capability contributes to organizational supply chain resilience remains limited. In particular, it remains unclear whether agentic AI creates resilience directly or whether organizations require interpretive capabilities to transform AI-generated intelligence into resilient responses.

A similar problem exists regarding Digital Twin Intelligence. Digital twins provide increasingly sophisticated representations and simulations of supply chains, yet access to an advanced virtual model does not automatically guarantee effective managerial interpretation. Organizations may possess substantial digital information while lacking the capacity to understand its strategic implications. Therefore, research needs to move beyond asking whether digital twins improve resilience toward explaining how digital twin intelligence is transformed into resilient cognition and action.

Another important problem concerns the conceptualization of resilience itself. Much of the literature evaluates resilience through operational dimensions such as recovery speed, flexibility, redundancy, responsiveness, and continuity. These dimensions are important, but they provide limited insight into the organization's ability to interpret uncertainty, revise assumptions, anticipate consequences, and maintain decision quality under disruption. This creates a need to examine the cognitive dimension of supply chain resilience.

Moreover, research frequently treats AI as an organizational technology without adequately examining how human decision-makers interact with intelligent systems. Complete reliance on either human judgment or autonomous AI may be problematic. Human decision-makers face cognitive limitations and information-processing constraints, whereas AI systems may lack contextual understanding, tacit knowledge, ethical awareness, and the ability to appropriately interpret unprecedented circumstances. Consequently, Human-AI Collaboration may represent a crucial condition determining whether organizational sensemaking ultimately produces stronger cognitive resilience.

The central research problem is therefore the absence of a sufficiently integrated explanation of how emerging autonomous AI and digital twin capabilities are transformed through organizational sensemaking into cognitive supply chain resilience, and under what conditions this transformation becomes stronger. Addressing this problem requires simultaneous consideration of technological capabilities, cognitive interpretation, resilience, and human-AI collaboration.

Research Gap

Several research gaps emerge from the contemporary literature. First, although artificial intelligence has received substantial attention in supply chain research, most existing studies focus on conventional AI, machine learning, predictive analytics, automation, or AI-enabled information processing (Smyth et al., 2024; Lin & Zhang, 2025). The emerging concept of Agentic AI Capability, involving autonomous reasoning, planning, interaction, and goal-oriented action, remains at an early stage within supply chain research. Existing agentic AI studies such as Jannelli et al. (2025) demonstrate its technological potential, but empirical organizational research examining its implications for supply chain capabilities remains comparatively limited.

Second, digital twin research has largely emphasized implementation, simulation, visibility, efficiency, operational optimization, and conventional supply chain resilience (Nakache et al., 2025; Liu et al., 2026). Less attention has been given to Digital Twin Intelligence as an organizational capability and how it improves the organization's cognitive capacity to understand and respond to complex supply chain conditions. Consequently, the interpretive mechanism through which digital twins contribute to resilience requires further investigation.

Third, prior studies frequently examine direct relationships between digital technologies and supply chain resilience. However, this approach does not sufficiently explain the organizational mechanism through which technological intelligence becomes resilience. Recent work by Kaneberg et al. (2026) and Rashid and Rasheed (2026) highlights the importance of sensemaking in resilience development, indicating a need to investigate Supply Chain Sensemaking Capability as a mediating mechanism between emerging digital capabilities and resilience.

Fourth, existing resilience literature predominantly conceptualizes supply chain resilience in terms of operational recovery, flexibility, redundancy, responsiveness, robustness, and adaptation (Stadtfeld & Gruchmann, 2024). Comparatively less empirical attention has been devoted to the cognitive foundations of resilience, particularly the capacity to recognize weak signals, interpret ambiguous events, revise assumptions, anticipate cascading consequences, and maintain adaptive decision-making. Therefore, examining Supply Chain Cognitive Resilience can extend conventional resilience research toward its cognitive and interpretive foundations.

Fifth, the literature has not adequately integrated Agentic AI Capability and Digital Twin Intelligence as simultaneous technological antecedents within a single supply chain resilience framework. Investigating them together is important because they represent complementary capabilities. Digital twins can provide real-time representations and simulation environments, whereas agentic AI can provide autonomous reasoning, analysis, coordination, and action.

Sixth, there remains limited understanding of the role of Human-AI Collaboration as a boundary condition between supply chain sensemaking and cognitive resilience. While AI can enhance information processing, human actors remain important for contextual interpretation, strategic judgment, validation, and handling unprecedented situations. Existing research has not sufficiently explained whether stronger collaboration between human decision-makers and AI systems enhances the ability of organizations to translate sensemaking into resilience.

Finally, the existing literature remains fragmented across research streams dealing separately with AI, digital twins, sensemaking, supply chain resilience, and human-AI interaction. The present study addresses this fragmentation by integrating two technological antecedents (AAIC and DTI), one cognitive mediator (SCSC), one cognitive resilience outcome (SCCR), and one human-technology boundary condition (HAIC) within a unified framework.

Purpose of the Study

The primary purpose of this study is to develop and empirically examine an integrated framework explaining how advanced digital capabilities contribute to Supply Chain Cognitive Resilience. Specifically, the study investigates the effects of Agentic AI Capability and Digital Twin Intelligence on Supply Chain Cognitive Resilience and examines whether these relationships operate through Supply Chain Sensemaking Capability.

The study further seeks to determine whether Human-AI Collaboration strengthens the relationship between Supply Chain Sensemaking Capability and Supply Chain Cognitive Resilience. By doing so, the research moves beyond a purely technology-centered explanation of supply chain resilience and considers the interaction between technological intelligence, organizational interpretation, and human judgment.

More broadly, the study seeks to contribute to emerging supply chain research by explaining how organizations can combine autonomous AI, intelligent digital representations, organizational sensemaking, and human expertise to develop supply chains that are not only operationally resilient but also cognitively capable of anticipating, interpreting, and adapting to unexpected disruptions.

Research Questions

Based on the identified research problem and research gaps, the study addresses the following research questions:

RQ1: How does Agentic AI Capability influence Supply Chain Sensemaking Capability?

RQ2: How does Digital Twin Intelligence influence Supply Chain Sensemaking Capability?

RQ3: How does Supply Chain Sensemaking Capability influence Supply Chain Cognitive Resilience?

RQ4: How does Agentic AI Capability influence Supply Chain Cognitive Resilience?

RQ5: How does Digital Twin Intelligence influence Supply Chain Cognitive Resilience?

RQ6: Does Supply Chain Sensemaking Capability mediate the relationship between Agentic AI Capability and Supply Chain Cognitive Resilience?

RQ7: Does Supply Chain Sensemaking Capability mediate the relationship between Digital Twin Intelligence and Supply Chain Cognitive Resilience?

RQ8: Does Human-AI Collaboration moderate the relationship between Supply Chain Sensemaking Capability and Supply Chain Cognitive Resilience, such that the relationship becomes stronger at higher levels of Human-AI Collaboration?

Research Objectives

In accordance with the research questions, the study seeks to achieve the following objectives:

RO1: To examine the effect of Agentic AI Capability on Supply Chain Sensemaking Capability.

RO2: To investigate the effect of Digital Twin Intelligence on Supply Chain Sensemaking Capability.

RO3: To determine the effect of Supply Chain Sensemaking Capability on Supply Chain Cognitive Resilience.

RO4: To examine the effect of Agentic AI Capability on Supply Chain Cognitive Resilience.

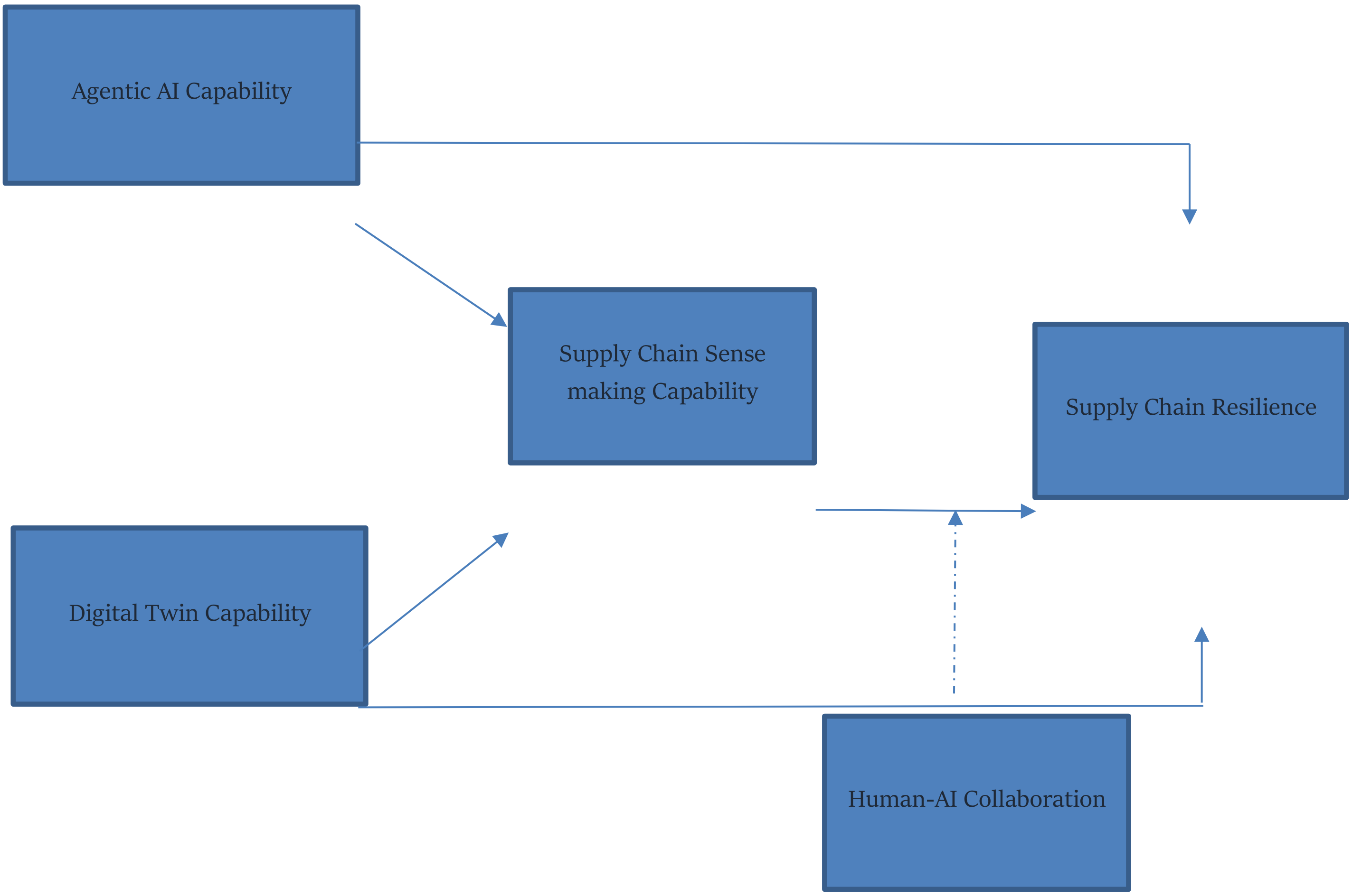
RO5: To investigate the effect of Digital Twin Intelligence on Supply Chain Cognitive Resilience.

RO6: To examine the mediating role of Supply Chain Sensemaking Capability in the relationship between Agentic AI Capability and Supply Chain Cognitive Resilience.

RO7: To examine the mediating role of Supply Chain Sensemaking Capability in the relationship between Digital Twin Intelligence and Supply Chain Cognitive Resilience.

RO8: To investigate the moderating role of Human-AI Collaboration in the relationship between Supply Chain Sensemaking Capability and Supply Chain Cognitive Resilience.

Conceptual Framework



Literature Review

Agentic AI Capability and Supply Chain Sensemaking Capability

Agentic AI represents an emerging generation of artificial intelligence capable of performing goal-oriented activities with comparatively greater autonomy than conventional analytical systems. Unlike traditional AI applications that primarily generate predictions or recommendations, agentic AI systems may reason about problems, interact with other agents, plan sequences of activities, monitor changes in their environment, and initiate actions toward predefined objectives. Within supply chains, such capabilities have considerable relevance because organizations continuously face fragmented information, demand fluctuations, supplier disruptions, logistics delays, geopolitical shocks, and changing customer requirements. Jannelli et al. demonstrate the emerging potential of LLM-based autonomous agents in supply chains by developing multi-agent approaches to consensus-seeking for decisions such as inventory coordination. Their research illustrates how agentic systems may process information, reason across alternatives, and support coordination among supply chain actors.

Supply chain sensemaking capability refers to the organization's ability to collect ambiguous or fragmented information, interpret its significance, develop a shared understanding of emerging events, and determine appropriate courses of action.

Sensemaking becomes especially important during disruptions because managers rarely possess complete information regarding the origin, magnitude, duration, and consequences of an unexpected event. Kaneberg et al. (2026) demonstrate that supply chain resilience is not activated automatically when organizations possess resources. Rather, organizations first interpret disruption experiences and translate those interpretations into resilience-oriented capabilities. Their findings show that sensemaking influences how organizations frame crises, assess their capacity to respond, and form expectations concerning future risks.

Agentic AI capability may significantly strengthen this interpretive process. Autonomous AI agents can continuously examine large volumes of structured and unstructured information, identify weak signals, compare alternatives, detect interdependencies, and communicate actionable insights. Such capabilities can expand organizational information-processing capacity and reduce delays between the appearance of a disruption signal and managerial recognition of its implications. Related evidence from AI-enabled supply chain research demonstrates that artificial intelligence supports information processing, risk detection, predictive decision-making, and supply chain resilience (Smyth et al., 2024; Smyth et al., 2025).

The importance of converting AI capabilities into organizational mechanisms is also supported outside the immediate supply chain domain. Ahmed et al. (2025) found that AI-powered organizational practices contribute to sustainable outcomes through intermediate organizational mechanisms such as learning and engagement. Although their research concerns HRM rather than supply chains, it reinforces the broader argument that the organizational value of AI often emerges through capabilities that convert technological intelligence into organizational knowledge and action.

Consequently, supply chains possessing stronger agentic AI capabilities should be better positioned to detect environmental changes, interpret disruption-related information, evaluate alternative explanations, and construct timely meanings from uncertain situations. Therefore:

H1: Agentic AI capability has a significant positive effect on supply chain sensemaking capability.

Digital Twin Intelligence and Supply Chain Sensemaking Capability

Digital twin technology has emerged as another important technological development in contemporary supply chain management. A digital twin establishes a dynamic virtual representation of physical assets, processes, facilities, or broader supply chain systems and continuously updates this representation using operational data. More advanced digital twins move beyond visualization by incorporating analytical, simulation, predictive, and decision-support capabilities. The term digital twin intelligence in the present study therefore reflects an organization's capability to use digitally synchronized representations of supply chain activities to monitor conditions, analyze relationships, anticipate consequences, and generate decision-relevant intelligence.

Recent research demonstrates considerable potential for digital twins in supply chain management. Nakache et al. (2025), in their review of digital twins in supply chains, emphasize their relevance for supply chain efficiency and resilience and identify substantial opportunities for applying digital twins to complex supply chain decision problems. Similarly, Liu et al. (2026) conclude that digital twin technology aligns closely with the informational and decision requirements associated with supply chain resilience because it enables monitoring, analysis, simulation, and decision support across different stages of disruption.

Digital twin intelligence can particularly strengthen sensemaking because organizational interpretation requires more than merely possessing information. Decision-makers must understand relationships between events, visualize possible consequences, evaluate alternative scenarios, and determine which signals require attention. Digital twins provide an environment in which managers can observe real-time supply chain conditions and virtually test the potential consequences of different disruption scenarios before decisions are implemented. Recent reviews indicate that digital twins can contribute to improved supply chain visibility, agility, decision-making, and resilience (Nakache et al., 2025; Liu et al., 2026).

This argument also corresponds with broader evidence concerning digitalization. Siddiqui et al. (2025) emphasize the importance of resilience and digitalization for supply chain performance, suggesting that digital capabilities are increasingly central to the ability of organizations to operate effectively in uncertain environments. Likewise, Javed et al. (2025), although examining digital platforms in an educational setting rather than supply chains, demonstrate more generally how digital platforms facilitate information access and technology-enabled processes. The common implication is that digital infrastructures become organizationally valuable when information generated through them contributes to improved understanding and decisions.

Digital twin intelligence should therefore strengthen managers' capacity to make sense of ambiguous supply chain situations by creating an integrated representation of supply chain conditions, highlighting interdependencies, supporting simulations, and enabling decision-makers to evaluate possible consequences of disruptions. Hence:

H2: Digital twin intelligence has a significant positive effect on supply chain sensemaking capability.

Supply Chain Sensemaking Capability and Supply Chain Cognitive Resilience

Supply chain resilience traditionally describes the capability of a supply chain to prepare for, respond to, recover from, and adapt to disruptions. However, increasing environmental complexity suggests that structural resources such as redundancy, inventory buffers, multiple suppliers, and flexible capacity alone may not sufficiently explain why some organizations respond more effectively to unexpected disturbances. Resilience also possesses an important cognitive component because organizations must recognize threats, interpret incomplete information, anticipate secondary consequences, prioritize alternative responses, and continuously revise their understanding as disruptions evolve. Stadtfeld and Gruchmann (2024) emphasize that resilience capabilities consist of bundles of practices and dynamic capabilities that evolve as organizations develop greater maturity in handling disruptions.

In the present framework, supply chain cognitive resilience refers to the organization's cognitive and interpretive capacity to remain alert to disruption signals, construct meaningful interpretations of uncertain events, revise assumptions, anticipate consequences, and develop adaptive responses despite environmental turbulence. This conceptualization builds upon contemporary supply chain resilience and sensemaking research rather than treating resilience simply as post-disruption recovery. Kaneberg et al. (2026) provide especially relevant evidence by demonstrating that resilience emerges through interpretive mechanisms. Their findings indicate that disruptions are actively interpreted and framed, and that these interpretations shape how organizations mobilize collaboration, flexibility, digitalization competence, and strategic monitoring.

Sensemaking therefore provides the cognitive foundation through which fragmented data are transformed into an understanding of what is occurring and what the organization should do next. When sensemaking capability is high, supply chain actors can recognize weak disruption signals, reduce interpretive ambiguity, exchange perspectives, challenge existing assumptions, and coordinate their understanding of threats. Such shared interpretations can improve anticipatory decision-making and prevent organizations from reacting to crises using outdated assumptions. Rashid and Rasheed (2026) similarly integrate organizational sensemaking into an AI-enabled supply chain resilience framework, reinforcing the importance of interpretation when organizations respond to digitally identified risks.

Therefore, organizations with stronger supply chain sensemaking capability should possess greater cognitive preparedness for disruptions and should be better able to translate uncertainty into coherent, adaptive responses. Accordingly:

H3: Supply chain sensemaking capability has a significant positive effect on supply chain cognitive resilience.

Agentic AI Capability and Supply Chain Cognitive Resilience

Artificial intelligence has increasingly become an important resource for improving the resilience of supply chains. AI technologies can enhance risk identification, demand forecasting, information processing, scenario analysis, logistics planning, and disruption response. Smyth et al. (2024), through a systematic review of AI and prescriptive analytics, identify substantial potential for AI to enable resilient supply chains by improving analytical and decision-making capabilities. More recent empirical evidence from Lin and Zhang (2025) demonstrates a positive connection between enterprise AI development and supply chain resilience, particularly through improvements in information transparency and organizational capabilities.

Agentic AI extends these benefits because it introduces greater autonomy, goal-directed reasoning, multi-step planning, and interaction among AI agents. Jannelli et al.'s work on agentic LLMs illustrates how autonomous agents can perform supply-chain-specific consensus-seeking and address coordination problems that traditionally require considerable human interaction. Rather than waiting for managers to manually query analytical systems, agentic AI can potentially observe environmental conditions, identify deviations, formulate alternative actions, coordinate information, and escalate strategically important issues.

These abilities have direct relevance to cognitive resilience because resilient organizations require rapid recognition of changing threats and the capacity to continuously revise responses. Machine learning and artificial intelligence research increasingly emphasizes the role of these technologies in providing insights, automation, and agility during disruption and recovery (Balan, 2025). Likewise, Siddiqui et al. (2025) connect digitalization and resilience within the supply chain performance context, highlighting the increasingly important role of digital capabilities in strengthening organizations' responses to uncertain environments.

Agentic AI capability can therefore increase the cognitive capacity available to supply chains by complementing human managers with continuous monitoring, advanced reasoning, pattern recognition, and autonomous analytical support. This increased cognitive bandwidth should help firms anticipate disruptions, recognize patterns that might otherwise remain unnoticed, and adapt more rapidly as events unfold. Thus:

H4: Agentic AI capability has a significant positive effect on supply chain cognitive resilience.

Digital Twin Intelligence and Supply Chain Cognitive Resilience

Digital twins can contribute to resilience because they allow organizations to virtually reproduce supply chain structures and continuously synchronize those representations with operational conditions. This enables organizations to examine not only what is currently happening but also what may happen under alternative disruption scenarios. Nakache et al. (2025) identify resilience as an important field of digital twin application, while Liu et al. (2026) systematically demonstrate how digital twin capabilities can support supply chains before, during, and after disruptive events.

The cognitive value of digital twin intelligence is particularly important. Traditional resilience decisions are often constrained by fragmented information and limited understanding of complex interdependencies. A disruption at a single supplier may affect production capacity, transport routes, customer fulfillment, working capital, and downstream partners simultaneously. Digital twin intelligence can make such interdependencies more visible and provide decision-makers with virtual environments for examining possible outcomes. Consequently, managers are better positioned to anticipate cascading consequences rather than merely respond after damage has already occurred.

Research examining digital twins in manufacturing supply chains has similarly identified their role in strengthening resilient and sustainable capabilities, while recent reviews emphasize their potential to improve supply chain visibility, agility, and decision quality. The findings of Siddiqui et al. (2025) concerning digitalization and supply chain resilience further reinforce the broader theoretical expectation that digitally enabled capabilities support effective supply chain responses and performance under uncertainty.

Digital twin intelligence should consequently strengthen cognitive resilience by enabling managers to visualize disruptions, anticipate cascading consequences, test alternative responses, learn from simulations, and continually update their understanding of the supply chain. Therefore:

H5: Digital twin intelligence has a significant positive effect on supply chain cognitive resilience.

Mediating Role of Supply Chain Sensemaking Capability Between Agentic AI Capability and Supply Chain Cognitive Resilience

Although agentic AI can provide advanced analytical and autonomous decision capabilities, technological intelligence alone does not guarantee that organizations will respond appropriately to disruptions. AI-generated signals must still be placed within organizational, operational, and strategic contexts. For example, an AI agent may identify an unusual increase in supplier lead time, but organizational actors must determine whether this represents temporary variation, an emerging supplier failure, geopolitical interference, a logistics bottleneck, or another systemic risk. The conversion of technological signals into contextually meaningful interpretation therefore represents an important intermediate process.

This argument is consistent with sensemaking theory, according to which organizations confronted with ambiguity construct interpretations that subsequently guide action. Kaneberg et al. (2026) demonstrate specifically in the supply-chain context that resilience-oriented dynamic capabilities are not automatically activated during crises. Instead, they are mobilized through interpretive processes in which organizations frame disruption experiences, evaluate resources, and develop expectations regarding future conditions.

Recent empirical research also supports the general logic of indirect technological effects. Smyth et al. (2025) examine AI-enabled information processing and identify organizational mechanisms such as mindfulness and flexibility as important for supply chain resilience. Similarly, Ahmed et al. (2025) demonstrate in an organizational context that AI-powered practices influence performance through learning and engagement mechanisms. These studies support a broader capability-based argument that AI creates stronger organizational outcomes when technological resources are translated through intermediate human and organizational capabilities.

Agentic AI capability should therefore strengthen the organization's ability to obtain and process disruption-related intelligence, whereas supply chain sensemaking capability should convert that intelligence into coherent interpretations that support anticipatory and adaptive responses. Sensemaking thus explains how agentic AI capability can ultimately contribute to cognitive resilience. Accordingly:

H6: Supply chain sensemaking capability significantly mediates the relationship between agentic AI capability and supply chain cognitive resilience.

Mediating Role of Supply Chain Sensemaking Capability Between Digital Twin Intelligence and Supply Chain Cognitive Resilience

Digital twin intelligence provides organizations with a sophisticated informational representation of their supply chain environment; however, access to real-time visualization and simulation does not automatically produce resilience. Managers must interpret what digital representations mean, determine which deviations are important, evaluate possible explanations, and convert simulations into coordinated strategic responses. Thus, the value of digital twin intelligence is likely to depend on an organization's ability to make sense of information generated by the digital twin.

Digital twins reduce informational fragmentation by integrating operational data and providing managers with an interconnected representation of supply chain activities. Nakache et al. (2025) explain that digital twins have substantial potential for improving both supply chain efficiency and resilience, while Liu et al. (2026) identify monitoring, analysis, and decision support as important digital twin functions across disruption stages. Yet these technological functions still require organizational interpretation. A simulation may indicate that a supplier shutdown will delay production, for example, but managers must evaluate the credibility of the simulation, interpret the strategic importance of the affected materials, understand stakeholder consequences, and select an appropriate response.

Sensemaking capability therefore functions as the bridge between technologically generated visibility and cognitively resilient action. Strong sensemaking allows decision-makers to contextualize digital-twin information, connect operational signals with previous experiences, question assumptions, establish shared interpretations, and translate simulations into meaningful responses. The findings of Kaneberg et al. (2026) are particularly relevant because they demonstrate that digitalization-related dynamic capabilities become resilience-producing through interpretive processes rather than merely through their existence.

Accordingly, digital twin intelligence is expected to enhance cognitive resilience partly because it improves the information available for interpretation, while sensemaking determines whether this information is transformed into adaptive understanding and action. Therefore:

H7: Supply chain sensemaking capability significantly mediates the relationship between digital twin intelligence and supply chain cognitive resilience.

Moderating Role of Human-AI Collaboration

Although supply chain sensemaking capability can facilitate resilience, the increasing involvement of artificial intelligence in supply chain decisions introduces an important question concerning how human judgment and machine intelligence should interact. AI systems possess significant advantages in processing large volumes of information, detecting statistical patterns, monitoring real-time events, and rapidly evaluating alternatives. Human decision-makers, however, provide contextual knowledge, ethical judgment, experiential understanding, intuition, stakeholder awareness, and an ability to interpret exceptional situations that may not be adequately represented in historical data. Effective supply chain decision-making may therefore depend increasingly on complementarity between human and artificial intelligence rather than complete substitution of one for the other.

Human-AI collaboration refers to arrangements in which humans and AI systems jointly contribute to information processing, interpretation, problem solving, and decision-making. Contemporary research treats this collaboration as potentially symbiotic because AI can increase analytical capacity while humans provide contextual interpretation and oversight. Research on human-AI collaboration has emphasized that effective collaboration can improve decision-making and organizational performance when the respective strengths of humans and AI are appropriately combined.

This complementarity is particularly important for supply chain sensemaking. Disruptions frequently involve novel events for which historical patterns provide incomplete guidance. AI may identify relationships across thousands of supplier, logistics, market, weather, or operational variables, but managers must determine whether identified patterns make strategic sense and whether automated recommendations adequately reflect organizational priorities. Human-AI collaboration therefore allows technologically generated intelligence to be challenged, interpreted, enriched with contextual knowledge, and converted into coordinated action.

Rashid and Rasheed (2026) directly bring AI-powered supply chain risk management and organizational sensemaking together in explaining supply chain resilience, highlighting the importance of combining digital intelligence with organizational interpretation. The broader organizational literature also suggests the importance of human capabilities alongside technological systems. Ahmed et al. (2025) demonstrate that learning and employee engagement matter in translating AI-powered practices into sustainable outcomes. Ahmed et al. (2025), in their study of transformational and green servant leadership, likewise emphasize the importance of human leadership capabilities for sustainability-related employee outcomes. Although these studies examine different organizational settings, collectively they reinforce the principle that technological systems achieve stronger results when supported by effective human capabilities and organizational processes.

When human-AI collaboration is high, supply chain actors can combine machine-generated patterns with managerial experience, validate alternative interpretations, correct algorithmic errors, incorporate tacit information, and reach more informed conclusions regarding disruptions. Consequently, sensemaking capability should translate more effectively into cognitive resilience. Conversely, when collaboration is weak, AI-generated intelligence may remain disconnected from managerial understanding, while human decision-makers may underutilize valuable analytical insights. Thus, the effect of supply chain sensemaking capability on cognitive resilience is expected to be stronger under conditions of effective human-AI collaboration.

H8: Human-AI collaboration significantly moderates the relationship between supply chain sensemaking capability and supply chain cognitive resilience, such that the positive relationship becomes stronger when human-AI collaboration is high.

Methodology

Research Design

This study adopts a quantitative, explanatory, and cross-sectional research design to examine the relationships among Agentic AI Capability (AAIC), Digital Twin Intelligence (DTI), Supply Chain Sensemaking Capability (SCSC), Supply Chain Cognitive Resilience (SCCR), and Human-AI Collaboration (HAIC). A quantitative approach is considered appropriate because the proposed relationships are expressed through theoretically developed hypotheses that require empirical testing using numerical data. The explanatory design enables the study to investigate the direct effects of AAIC and DTI on SCSC and SCCR, as well as the mechanism through which SCSC mediates these relationships. In addition, the study investigates the moderating role of HAIC in the relationship between SCSC and SCCR. A cross-sectional approach is employed whereby data are collected from respondents at a single point in time. This design is suitable for examining perceptions, organizational capabilities, and technology-related practices across supply chain professionals and is consistent with contemporary empirical research examining digitalization, artificial intelligence, and supply chain resilience (Siddiqui et al., 2025; Lin & Zhang, 2025).

The conceptual framework is structured around two technological antecedents, Agentic AI Capability and Digital Twin Intelligence, which are expected to influence Supply Chain Cognitive Resilience, both directly and indirectly through Supply Chain Sensemaking Capability. Furthermore, Human-AI Collaboration is incorporated as a moderator between SCSC and SCCR. This research design therefore permits simultaneous examination of direct, indirect, and interaction effects within a single structural model.

Population and Sampling

The target population of the study consists of professionals working in organizations with supply chain, procurement, logistics, operations, inventory, manufacturing, distribution, information technology, and digital transformation functions. Particular emphasis is placed on respondents who possess sufficient knowledge of their organizations' supply chain processes and exposure to digital technologies, artificial intelligence, analytics, automation, or digital supply chain systems. Appropriate respondents may include supply chain managers, procurement managers, logistics managers, operations managers, warehouse and inventory managers, IT and digital transformation professionals, planning managers, and other executives involved in supply chain decision-making.

The study employs a purposive sampling technique because the constructs under investigation, particularly agentic AI, digital twin intelligence, and human-AI collaboration, require respondents with relevant professional knowledge and organizational exposure. Purposive sampling enables researchers to select respondents who are capable of providing meaningful information concerning technology-enabled supply chain practices. To improve the relevance of responses, screening questions should be included at the beginning of the questionnaire to determine whether respondents are involved in supply chain-related activities and whether their organizations use or are familiar with advanced digital technologies.

The required sample size should be determined using statistical power analysis, considering the complexity of the proposed structural model, number of predictors, anticipated effect size, significance level, and desired statistical power. For PLS-SEM analysis, obtaining a sufficiently large sample is important to ensure stable parameter estimates and adequate statistical power. Therefore, the study should aim to obtain approximately 300–400 valid responses, subject to confirmation through an appropriate power analysis. This sample range should provide an adequate empirical basis for assessing the measurement and structural models and testing mediation and moderation effects.

Data Collection Procedure

Primary data are collected through a structured self-administered questionnaire distributed among eligible supply chain and related professionals. The questionnaire may be administered electronically through Google Forms or another secure online survey platform and, where feasible, through direct distribution to professionals working in relevant organizations. Respondents should receive a brief explanation of the purpose of the research and should be informed that participation is voluntary and that their responses will be used solely for academic and research purposes.

Before full-scale data collection, the questionnaire should undergo expert review and pilot testing. Academicians with expertise in supply chain management, artificial intelligence, and quantitative research, together with relevant industry professionals, may be requested to assess the questionnaire for content relevance, clarity, wording, and contextual appropriateness. Subsequently, a pilot study involving approximately 30–50 respondents may be conducted to identify ambiguous questions and assess the preliminary reliability of the measurement scales. Necessary modifications should be made before launching the final survey.

To reduce the possibility of common method bias, respondents should be assured of anonymity and confidentiality, and the questionnaire should clearly state that there are no right or wrong answers. Items measuring different constructs should be clearly organized, and respondents should be encouraged to provide responses based on actual organizational practices rather than socially desirable expectations. After data collection, responses should be screened for missing values, incomplete questionnaires, straight-lining, duplicate responses, and other indications of careless responding before proceeding to statistical analysis.

Measurement Instrument

The study uses a structured questionnaire comprising two major sections. The first section collects respondents' demographic and organizational information, including gender, age, educational qualification, professional experience, job designation, organizational sector, organization size, and experience with digital or AI-enabled supply chain technologies. Such information facilitates an understanding of the characteristics of the sample and provides an appropriate context for interpreting the findings.

The second section contains measurement items for the five principal constructs: Agentic AI Capability (AAIC), Digital Twin Intelligence (DTI), Supply Chain Sensemaking Capability (SCSC), Supply Chain Cognitive Resilience (SCCR), and Human-AI Collaboration (HAIC). Because several of these concepts represent emerging research areas, measurement items should be adapted carefully from established scales relating to AI capability, digital technology capability, digital twins, organizational sensemaking, supply chain resilience, and human-AI collaboration. The wording should be modified only where necessary to ensure consistency with the supply chain context while retaining the conceptual meaning of the original scales.

All constructs should preferably be measured using a five-point Likert scale, ranging from 1 = Strongly Disagree to 5 = Strongly Agree. Multi-item measurement should be used for each construct to capture its conceptual domain more comprehensively. Before testing the structural relationships, the psychometric properties of all scales should be examined to establish their reliability and validity. The questionnaire should also be reviewed for content and face validity by academic and industry experts before final administration.

Data Analysis Technique

The collected data are analyzed using a combination of SPSS and SmartPLS. SPSS may initially be used for data coding, cleaning, missing-value assessment, descriptive statistics, demographic profiling, and preliminary examination of the dataset. Subsequently, Partial Least Squares Structural Equation Modeling (PLS-SEM) is performed using SmartPLS to evaluate the proposed theoretical model.

PLS-SEM is appropriate for the present study because the proposed framework contains multiple endogenous and exogenous constructs and simultaneously examines direct effects, mediation effects, and a moderation effect. Moreover, the research focuses on explaining and predicting Supply Chain Cognitive Resilience through emerging technological and organizational capabilities. The analysis is conducted in two stages: measurement model assessment followed by structural model assessment.

Measurement Model Assessment

The measurement model is assessed to establish the reliability, convergent validity, and discriminant validity of the constructs before testing the hypotheses. Indicator reliability is first evaluated through the outer loadings of individual measurement items. Ideally, indicators should exhibit outer loadings of approximately 0.708 or above, although indicators with moderately lower loadings may be retained when theoretically justified and when overall reliability and convergent validity remain satisfactory.

Internal consistency reliability is assessed through Cronbach's alpha, rho_A, and Composite Reliability (CR). Values of 0.70 or above generally demonstrate acceptable internal consistency reliability. Convergent validity is examined using Average Variance Extracted (AVE), with an AVE value of 0.50 or greater indicating that the construct explains at least half of the variance in its indicators.

Discriminant validity is assessed primarily through the Heterotrait-Monotrait ratio (HTMT). HTMT values below 0.85, or below 0.90 under a more liberal criterion, indicate adequate distinction between constructs. The Fornell-Larcker criterion and examination of indicator cross-loadings may additionally be reported as supplementary evidence of discriminant validity. These assessments establish whether AAIC, DTI, SCSC, SCCR, and HAIC represent empirically distinguishable concepts.

Structural Model Assessment

Following satisfactory establishment of measurement quality, the structural model is evaluated to test the proposed hypotheses. Before examining structural relationships, collinearity among predictor constructs is assessed using the Variance Inflation Factor (VIF). Acceptable VIF values indicate that multicollinearity does not substantially distort the estimated relationships.

The direct relationships proposed in H1–H5 are assessed using standardized path coefficients (β), t-values, and p-values. Statistical significance is evaluated through the bootstrapping procedure in SmartPLS, preferably using 5,000 bootstrap subsamples. At a 5% significance level, relationships with $p < 0.05$ are considered statistically significant.

The explanatory power of the model is examined through the coefficient of determination (R^2) for the endogenous constructs, particularly SCSC and SCCR. Higher R^2 values indicate that greater proportions of variance are explained by the predictor variables. In addition, effect size (f^2) should be assessed to determine the relative contribution of individual exogenous constructs to endogenous variables. The model's predictive relevance can be examined using Q^2 or SmartPLS predictive procedures, as appropriate.

Mediation Analysis

The mediating role of Supply Chain Sensemaking Capability is assessed for H6 and H7. Specifically, the study evaluates the indirect pathway:

AAIC → SCSC → SCCR

and:

DTI → SCSC → SCCR

Bootstrapping with 5,000 subsamples is used to estimate the significance of the specific indirect effects. A statistically significant indirect effect provides evidence of mediation. The direct and indirect effects should then be considered jointly to determine whether the results indicate partial, full/indirect-only, or complementary mediation, depending on the direction and significance of the corresponding effects.

Moderation Analysis

The moderating effect proposed in H8 is assessed by constructing an interaction term between Supply Chain Sensemaking Capability and Human-AI Collaboration (SCSC × HAIC). The interaction term is then used to predict Supply Chain Cognitive Resilience. A statistically significant interaction coefficient indicates the presence of moderation.

If the interaction effect is positive and statistically significant, it indicates that higher levels of Human-AI Collaboration strengthen the positive effect of Supply Chain Sensemaking Capability on Supply Chain Cognitive Resilience. To facilitate interpretation, a simple slope analysis should be conducted by examining the relationship between SCSC and SCCR at low, medium, and high levels of HAIC. The interaction should also be presented graphically to illustrate how the SCSC–SCCR relationship changes according to the level of Human-AI Collaboration.

Findings

The empirical analysis was conducted using Partial Least Squares Structural Equation Modeling (PLS-SEM). The final dataset consisted of 305 valid responses. The analysis followed the two-stage procedure recommended for PLS-SEM, beginning with an assessment of the measurement model to establish construct reliability, convergent validity, and discriminant validity, followed by evaluation of the structural model to test the proposed direct, mediating, and moderating relationships. The measurement model results demonstrate satisfactory psychometric properties across all five constructs, namely Agentic AI Capability (AAIC), Digital Twin Capability (DTC), Human-AI Collaboration (HAIC), Supply Chain Sensemaking Capability (SCSC), and Supply Chain Resilience (SCR). The structural model further demonstrates substantial explanatory and predictive capabilities and provides empirical support for all eight proposed hypotheses.

Measurement Model Assessment

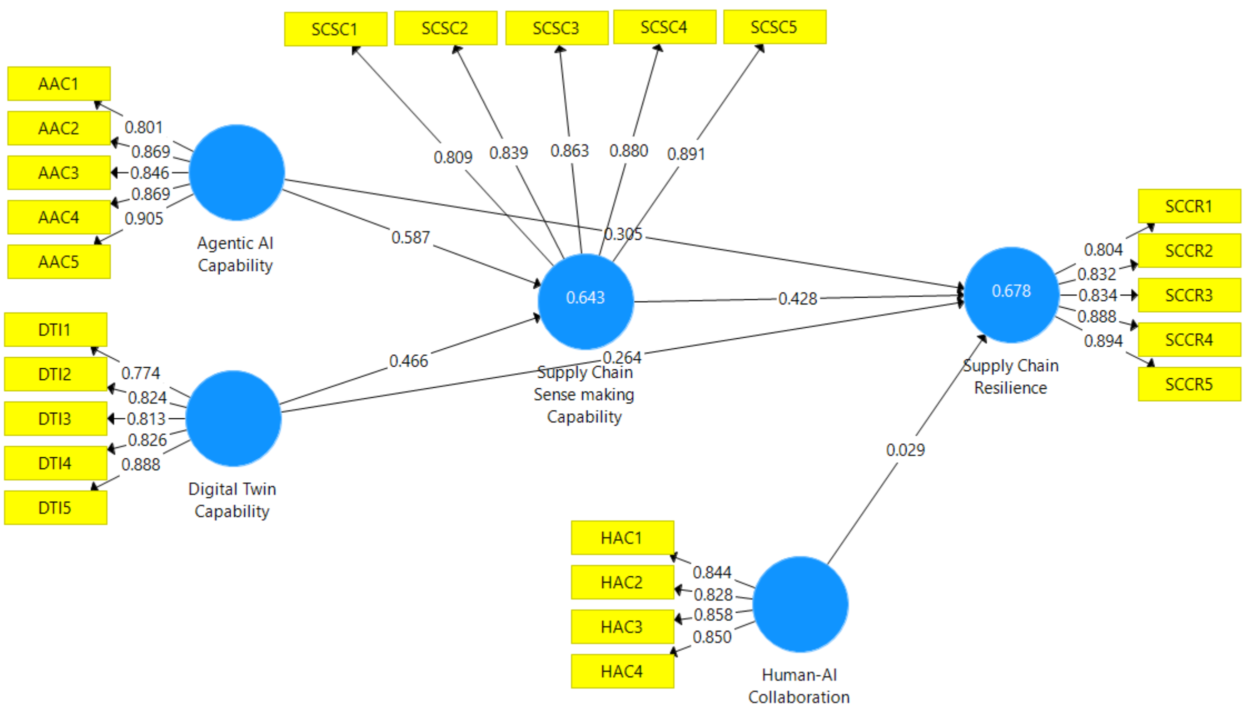


Figure 1 Measurement model

The measurement model was evaluated using Cronbach's alpha, rho_A, Composite Reliability (CR), Average Variance Extracted (AVE), the Fornell-Larcker criterion, Heterotrait-Monotrait Ratio (HTMT), and model fit indices. The findings demonstrate satisfactory internal consistency, convergent validity, discriminant validity, and overall model fit.

Table 1. Construct Reliability and Validity

Construct	Cronbach's Alpha	rho_A	Composite Reliability	AVE
Agentic AI Capability	0.911	0.916	0.933	0.737
Digital Twin Capability	0.883	0.887	0.914	0.682
Human-AI Collaboration	0.868	0.880	0.909	0.714
Supply Chain Resilience	0.904	0.908	0.929	0.725
Supply Chain Sensemaking Capability	0.909	0.914	0.932	0.734

Table 1 demonstrates that all constructs possess strong internal consistency reliability. Cronbach's alpha values range from 0.868 to 0.911, exceeding the recommended threshold of 0.70. Similarly, rho_A values range from 0.880 to 0.916, while Composite Reliability values range from 0.909 to 0.933. These findings demonstrate that the measurement items consistently represent their respective latent constructs.

Convergent validity was assessed through AVE. All AVE values are substantially above the recommended minimum threshold of 0.50, ranging from 0.682 to 0.737. Agentic AI Capability reports the highest AVE of 0.737, followed by Supply Chain Sensemaking Capability at 0.734, Supply Chain Resilience at 0.725, Human-AI Collaboration at 0.714, and Digital Twin Capability at 0.682. Thus, each construct explains more than 50% of the variance in its corresponding indicators. The results therefore establish satisfactory reliability and convergent validity of the measurement model.

Discriminant Validity

Table 2. Fornell-Larcker Criterion

Construct	AAIC	DTC	HAIC	SCR	SCSC
Agentic AI Capability	0.859				
Digital Twin Capability	0.148	0.826			
Human-AI Collaboration	0.201	0.168	0.845		
Supply Chain Resilience	0.631	0.550	0.233	0.851	
Supply Chain Sensemaking Capability	0.656	0.553	0.230	0.780	0.857

The Fornell-Larcker criterion confirms adequate discriminant validity. The square root of AVE for each construct, presented on the diagonal, is greater than its correlations with the other constructs. For example, the square root of AVE for Agentic AI Capability is 0.859, which exceeds its highest correlation of 0.656 with Supply Chain Sensemaking Capability. Similarly, the diagonal values for Digital Twin Capability (0.826), Human-AI Collaboration (0.845), Supply Chain Resilience (0.851), and Supply Chain Sensemaking Capability (0.857) exceed their corresponding inter-construct correlations. These findings indicate that each construct captures a concept that is empirically distinguishable from the other constructs included in the model.

Table 3. Heterotrait-Monotrait Ratio (HTMT)

Construct	AAIC	DTC	HAIC	SCR	SCSC
Agentic AI Capability	—				
Digital Twin Capability	0.162	—			
Human-AI Collaboration	0.225	0.187	—		
Supply Chain Resilience	0.690	0.613	0.256	—	
Supply Chain Sensemaking Capability	0.717	0.615	0.254	0.856	—

The HTMT results provide further evidence of discriminant validity. HTMT values range from 0.162 to 0.856 and remain below the commonly accepted threshold of 0.90. The highest HTMT value is observed between Supply Chain Sensemaking Capability and Supply Chain Resilience (0.856), which remains within the acceptable criterion. Consequently, discriminant validity is established across all five constructs.

Model Fit

Table 4. Model Fit Summary

Fit Index	Saturated Model	Estimated Model
SRMR	0.043	0.043
d_ULS	0.552	0.561
Chi-Square	461.643	461.665
NFI	0.911	0.911

The model fit statistics indicate that the proposed model provides an acceptable representation of the observed data. The Standardized Root Mean Square Residual (SRMR) values for both the saturated and estimated models are approximately 0.043, substantially below the recommended maximum value of 0.08. Moreover, the Normed Fit Index (NFI) is approximately 0.911, exceeding the generally acceptable value of 0.90. Taken together, the model fit results provide additional support for the adequacy of the proposed measurement and structural framework.

Structural Model Assessment

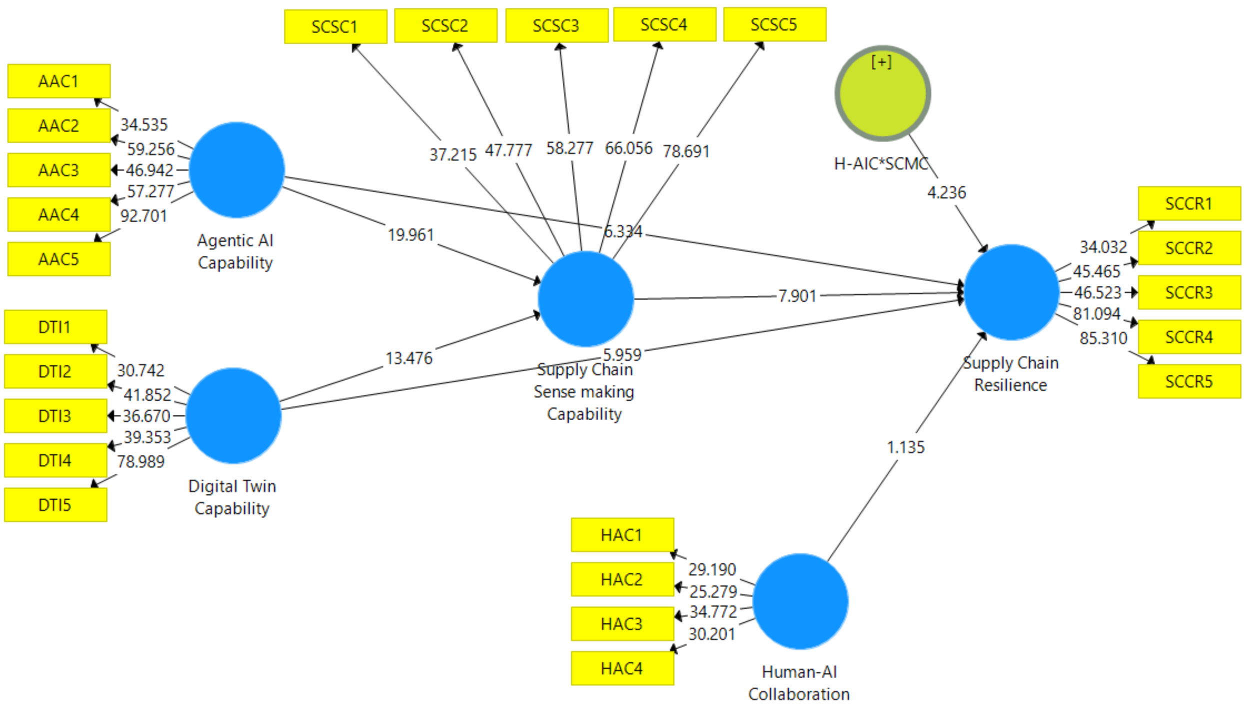


Figure 2 Structural model with moderation effect

After establishing the reliability and validity of the measurement model, the structural model was assessed to evaluate its explanatory power, predictive relevance, and proposed causal relationships. The analysis considered R^2, adjusted R^2, Q^2, standardized path coefficients, t-values, p-values, indirect effects, and the interaction effect.

Table 5. R^2 and Predictive Relevance

Endogenous Construct	R^2	Adjusted R^2	Q^2
Supply Chain Resilience	0.678	0.673	0.494
Supply Chain Sensemaking Capability	0.643	0.641	0.466

The coefficient of determination demonstrates substantial explanatory power. The model explains approximately 67.8% of the variance in Supply Chain Resilience (R^2 = 0.678), with an adjusted R^2 of 0.673. This indicates that Agentic AI Capability, Digital Twin Capability, Supply Chain Sensemaking Capability, Human-AI Collaboration, and the interaction between HAIC and SCSC collectively provide considerable explanatory power for supply chain resilience.

Similarly, Agentic AI Capability and Digital Twin Capability jointly explain approximately 64.3% of the variance in Supply Chain Sensemaking Capability (R^2 = 0.643), with an adjusted R^2 of 0.641. These results demonstrate that the two advanced technological capabilities are important predictors of organizational supply chain sensemaking.

Predictive relevance was evaluated through Stone-Geisser's Q^2. Supply Chain Resilience has a Q^2 value of 0.494, while Supply Chain Sensemaking Capability has a Q^2 value of 0.466. Since both values are substantially greater than zero, the model demonstrates strong predictive relevance for its endogenous constructs.

Hypothesis Testing

Bootstrapping was employed to determine the statistical significance of the structural relationships. The results of the direct, indirect, and moderating effects are summarized below.

Table 6. Direct and Indirect Pathways

Hyp.	Relationship	β	T Value	P Value	Result
H1	AAIC → SCSC	0.587	19.961	<0.001	Supported
H2	DTC → SCSC	0.466	13.476	<0.001	Supported
H3	SCSC → SCR	0.442	7.901	<0.001	Supported
H4	AAIC → SCR	0.304	6.334	<0.001	Supported
H5	DTC → SCR	0.260	5.959	<0.001	Supported
H6	AAIC → SCSC → SCR	0.260	7.603	<0.001	Supported
H7	DTC → SCSC → SCR	0.206	6.546	<0.001	Supported
H8	SCSC × HAIC → SCR	0.112	4.236	<0.001	Supported

The structural results provide support for all eight hypotheses. H1 proposed that Agentic AI Capability positively influences Supply Chain Sensemaking Capability. The relationship is positive and highly significant ($\beta = 0.587$, $t = 19.961$, $p < 0.001$), supporting H1. This is also the strongest technological antecedent of SCSC, suggesting that autonomous AI capabilities play a particularly important role in enabling organizations to detect, process, and interpret supply chain information.

H2 proposed a positive effect of Digital Twin Capability on Supply Chain Sensemaking Capability. The relationship is also statistically significant ($\beta = 0.466$, $t = 13.476$, $p < 0.001$), providing support for H2. The result suggests that digital twin capabilities improve organizational sensemaking by allowing decision-makers to visualize interconnected supply chain processes, interpret real-time conditions, and evaluate alternative disruption scenarios.

H3 proposed that Supply Chain Sensemaking Capability positively influences Supply Chain Resilience. The results demonstrate a strong and statistically significant relationship ($\beta = 0.442$, $t = 7.901$, $p < 0.001$), supporting H3. This finding indicates that the ability to interpret uncertain events, develop meaningful understanding, and coordinate interpretations plays an important role in strengthening the organization's resilience.

H4 predicted a direct positive relationship between Agentic AI Capability and Supply Chain Resilience. This relationship is significant ($\beta = 0.304$, $t = 6.334$, $p < 0.001$), supporting H4. Agentic AI therefore contributes to resilience not only through sensemaking but also directly by improving continuous monitoring, autonomous analysis, risk identification, and adaptive decision support.

H5 proposed that Digital Twin Capability positively affects Supply Chain Resilience. The relationship is positive and significant ($\beta = 0.260$, $t = 5.959$, $p < 0.001$), supporting H5. This suggests that digital twins can directly improve supply chain resilience by enabling organizations to monitor conditions, simulate disruption scenarios, anticipate cascading consequences, and evaluate alternative responses.

Mediation Analysis

The mediation analysis examined whether Supply Chain Sensemaking Capability transmits the effects of Agentic AI Capability and Digital Twin Capability to Supply Chain Resilience.

The specific indirect effect of Agentic AI Capability on Supply Chain Resilience through Supply Chain Sensemaking Capability is positive and statistically significant ($\beta = 0.260$, $t = 7.603$, $p < 0.001$). The 95% bootstrap confidence interval ranges approximately from 0.188 to 0.327, which does not contain zero. Therefore, H6 is supported.

Importantly, the direct effect of Agentic AI Capability on Supply Chain Resilience also remains positive and significant ($\beta = 0.304$, $p < 0.001$). Consequently, Supply Chain Sensemaking Capability provides partial/complementary mediation between Agentic AI Capability and Supply Chain Resilience. This indicates that agentic AI strengthens resilience both directly and indirectly by improving the organization's ability to interpret and make sense of supply chain conditions.

Similarly, the indirect effect of Digital Twin Capability on Supply Chain Resilience through Supply Chain Sensemaking Capability is statistically significant ($\beta = 0.206$, $t = 6.546$, $p < 0.001$). The corresponding 95% confidence interval extends approximately from 0.143 to 0.267 and does not include zero. H7 is therefore supported.

The direct effect of Digital Twin Capability on Supply Chain Resilience also remains significant ($\beta = 0.260$, $p < 0.001$), indicating partial/complementary mediation. Digital twin capability therefore strengthens resilience through two channels: directly through its monitoring, simulation, and decision-support capabilities and indirectly by enhancing organizational sensemaking.

These results provide an important contribution because they demonstrate that technology alone does not fully explain resilience. A meaningful portion of the effects of both Agentic AI Capability and Digital Twin Capability operates through the organization's ability to interpret technologically generated information and transform it into meaningful understanding.

Moderation Analysis

H8 proposed that Human-AI Collaboration strengthens the positive relationship between Supply Chain Sensemaking Capability and Supply Chain Resilience. The interaction effect SCSC × HAIC → SCR is positive and statistically significant ($\beta = 0.112$, $t = 4.236$, $p < 0.001$), providing empirical support for H8.

The positive interaction coefficient indicates that the contribution of Supply Chain Sensemaking Capability to resilience becomes stronger as Human-AI Collaboration increases. In other words, organizations are better able to transform their interpretation of complex supply chain information into resilient responses when human decision-makers and AI systems work collaboratively.

Interestingly, the standalone direct effect of Human-AI Collaboration on Supply Chain Resilience is not statistically significant ($\beta = 0.035$, $t = 1.135$, $p = 0.257$). This result is theoretically important because it suggests that simply possessing higher levels of Human-AI Collaboration may not independently produce resilience. Instead, its value emerges primarily as an enabling or strengthening condition that improves the translation of organizational sensemaking into resilient supply chain responses.

Overall, the moderation result supports the argument that human and artificial intelligence capabilities are complementary. AI can contribute computational speed, continuous data processing, pattern recognition, and predictive intelligence, while human decision-makers provide contextual knowledge, experience, intuition, strategic judgment, and interpretation. Their effective collaboration strengthens the conversion of sensemaking into supply chain resilience.

Overall Findings

Overall, the empirical results provide strong support for the proposed conceptual framework. All eight hypotheses are supported. Agentic AI Capability and Digital Twin Capability significantly strengthen Supply Chain Sensemaking Capability and Supply Chain Resilience. Supply Chain Sensemaking Capability itself significantly improves Supply Chain Resilience and partially mediates the effects of both technological capabilities. Human-AI Collaboration further strengthens the relationship between sensemaking and resilience.

Among the antecedents of Supply Chain Sensemaking Capability, Agentic AI Capability demonstrates the stronger effect ($\beta = 0.587$) compared with Digital Twin Capability ($\beta = 0.466$). Supply Chain Sensemaking Capability also exhibits a substantial direct relationship with resilience ($\beta = 0.442$). The model explains 64.3% of SCSC and 67.8% of SCR, while Q^2 values of 0.466 and 0.494 respectively demonstrate strong predictive relevance. Collectively, these results indicate that technologically advanced supply chains become resilient not simply by adopting sophisticated digital tools, but by developing the organizational capability to interpret the intelligence generated by those technologies and combining that interpretation with effective human-AI collaboration.

Discussion

The findings provide important insights into how emerging digital capabilities contribute to contemporary supply chain resilience. The significant positive relationship between Agentic AI Capability and Supply Chain Sensemaking Capability indicates that autonomous and intelligent AI systems can considerably improve the ability of organizations to interpret complex supply chain environments. This finding extends existing AI-enabled supply chain literature, which has generally emphasized predictive analytics, information processing, and risk detection (Smyth et al., 2024; Lin & Zhang, 2025), by demonstrating that the value of advanced AI also lies in strengthening organizational interpretation. Agentic AI can continuously monitor multiple information sources, identify weak signals, recognize emerging patterns, and support managers in developing a clearer understanding of uncertain supply chain conditions.

Digital Twin Capability also significantly enhances Supply Chain Sensemaking Capability. This result supports the growing literature highlighting the contribution of digital twins to supply chain monitoring, simulation, visibility, and disruption management (Nakache et al., 2025; Liu et al., 2026). By integrating real-time information into virtual representations of supply chain processes, digital twins allow managers to understand complex interdependencies and examine potential consequences before taking action. The finding therefore extends digital twin research by demonstrating that their contribution is not merely operational. Digital twins also strengthen the cognitive and interpretive processes underlying effective supply chain management.

The significant positive effect of Supply Chain Sensemaking Capability on Supply Chain Resilience provides particularly important evidence for the cognitive foundations of resilience. Organizations capable of identifying meaningful signals, interpreting ambiguous events, challenging existing assumptions, and developing shared understanding are better positioned to anticipate and respond to disruptions. This finding is consistent with Kaneberg et al. (2026), who emphasize interpretive processes in resilience development, and with Rashid and Rasheed (2026), who connect organizational sensemaking with AI-enabled supply chain risk management and resilience.

The significant direct effects of both Agentic AI Capability and Digital Twin Capability on Supply Chain Resilience further indicate that advanced digital technologies provide immediate resilience benefits. Agentic AI can improve autonomous monitoring, rapid analysis, coordination, and adaptive responses, whereas digital twins provide visibility, scenario simulation, and an integrated understanding of supply chain operations. These findings are broadly consistent with Siddiqui et al. (2025), who demonstrate the importance of digitalization and resilience for supply chain performance.

The mediation results deepen this explanation. Supply Chain Sensemaking Capability partially mediates both technological relationships, demonstrating that AAIC and DTC do not create resilience exclusively through their technical functionalities. Instead, part of their organizational value emerges because they improve the quality of information available for interpretation and enable managers to construct more accurate and timely understandings of disruption. The coexistence of significant direct and indirect effects demonstrates complementary mechanisms through which emerging digital technologies create resilient supply chains.

Finally, the significant moderating effect of Human-AI Collaboration indicates that the relationship between sensemaking and resilience depends partly on how effectively human decision-makers collaborate with intelligent systems. This result challenges the assumption that greater AI autonomy necessarily reduces the importance of human participation. Instead, advanced AI appears to increase the strategic importance of human interpretation. Human experience, contextual understanding, intuition, and strategic judgment complement the computational capabilities of AI, enabling organizations to translate complex intelligence into effective resilient actions.

Conclusion

This study examined the influence of Agentic AI Capability and Digital Twin Capability on Supply Chain Resilience, with Supply Chain Sensemaking Capability serving as a mediating mechanism and Human-AI Collaboration acting as a moderator. The empirical findings provide strong support for the proposed framework, as all eight hypotheses were statistically supported.

Agentic AI Capability significantly improves both Supply Chain Sensemaking Capability and Supply Chain Resilience, demonstrating the strategic importance of autonomous AI systems in monitoring complex environments, processing information, identifying disruption signals, and facilitating adaptive responses. Digital Twin Capability similarly exerts significant positive effects on both sensemaking and resilience, confirming the value of real-time virtual representations and simulation capabilities in improving organizational understanding and disruption preparedness.

Supply Chain Sensemaking Capability emerged as a particularly important mechanism in the model. It directly strengthens Supply Chain Resilience and partially mediates the effects of both Agentic AI Capability and Digital Twin Capability. These results demonstrate that technological sophistication alone is insufficient to explain resilience. Organizations must be capable of interpreting technologically generated information, developing meaningful understandings of uncertain events, and translating those interpretations into appropriate responses.

Furthermore, Human-AI Collaboration significantly strengthens the relationship between Supply Chain Sensemaking Capability and Supply Chain Resilience. Interestingly, HAIC does not have a significant standalone direct effect on resilience, indicating that its primary contribution lies in enhancing the effectiveness with which sensemaking is converted into resilient action. Overall, the study demonstrates that resilient digital supply chains emerge through the integration of advanced technological intelligence, organizational sensemaking, and effective collaboration between humans and AI systems.

Managerial Implications

The findings offer several important implications for supply chain managers and organizational decision-makers. First, organizations should move beyond viewing AI merely as an automation or forecasting tool and begin developing Agentic AI capabilities that support continuous monitoring, autonomous information processing, disruption detection, scenario evaluation, and coordinated decision support. Investment decisions should therefore consider not only the technical sophistication of AI systems but also their ability to enhance organizational understanding and responsiveness.

Second, managers should invest strategically in Digital Twin Capability by integrating real-time operational data, supplier information, logistics conditions, inventory positions, and disruption scenarios into dynamic digital representations of the supply chain. Digital twins should not be treated simply as visualization tools. Their greatest value may arise when they are integrated into managerial decision processes and used for scenario analysis, risk anticipation, and organizational learning.

Third, organizations should deliberately develop Supply Chain Sensemaking Capability. Managers should establish mechanisms through which information generated by AI systems and digital twins can be discussed, interpreted, challenged, and translated into coordinated actions. Cross-functional disruption-response teams, real-time intelligence dashboards, scenario-planning sessions, post-disruption reviews, and knowledge-sharing mechanisms can help organizations convert large volumes of digital information into meaningful strategic understanding.

Fourth, organizations should focus on Human-AI Collaboration rather than complete AI substitution. The significant moderation effect indicates that AI creates greater resilience value when combined with human judgment. Managers should therefore design decision processes in which AI performs data-intensive analytical tasks while experienced employees validate recommendations, contribute contextual knowledge, identify exceptional circumstances, and exercise strategic judgment. Training employees to understand AI-generated recommendations and creating clear protocols for human oversight will be increasingly important.

Finally, the substantial R^2 values indicate that these capabilities collectively explain a considerable proportion of supply chain resilience. Senior management should therefore consider AI capability, digital twin capability, sensemaking, and human-AI collaboration as interconnected components of a broader digital resilience strategy, rather than implementing each technology independently.

Recommendations

Organizations seeking to strengthen supply chain resilience should prioritize the development of integrated digital and cognitive capabilities. Firms should invest in agentic AI systems capable of continuous monitoring, autonomous analysis, early-warning detection, and intelligent decision support while maintaining appropriate human oversight. Digital twin systems should be integrated with real-time supply chain data to enable organizations to visualize operations, identify vulnerabilities, simulate disruption scenarios, and evaluate alternative responses before implementing decisions.

Organizations should also develop structured processes for supply chain sensemaking. Supply chain managers should be encouraged to combine information from AI systems, digital twins, suppliers, customers, logistics partners, and internal operational functions when evaluating potential disruptions. Regular scenario planning, risk review meetings, cross-functional information sharing, and post-disruption learning exercises can strengthen the organization's ability to interpret ambiguous conditions.

Particular attention should be given to Human-AI Collaboration. Organizations should provide employees with training that enables them to understand AI-generated information, critically evaluate recommendations, identify potential algorithmic limitations, and incorporate contextual knowledge into decisions. Rather than replacing experienced supply chain professionals, organizations should use AI to augment their analytical and decision-making capabilities.

Finally, organizations should establish governance mechanisms addressing AI transparency, data quality, cybersecurity, accountability, and human oversight. As supply chains increasingly rely on autonomous technologies, resilience will depend not only on technological capability but also on whether these systems are trusted, understood, appropriately governed, and effectively integrated into organizational decision processes.

Future Research Recommendations

Although the study provides important insights, several opportunities remain for future research. First, the cross-sectional design limits the ability to observe how Agentic AI Capability, Digital Twin Capability, sensemaking, and resilience evolve over time. Future studies could employ longitudinal designs to examine whether increasing technological maturity produces corresponding changes in supply chain resilience.

Second, future research could use experimental or simulation-based designs to examine how managers actually respond to AI-generated recommendations and digital twin scenarios during simulated supply chain disruptions. Such research could provide stronger evidence concerning causal mechanisms and human-AI decision dynamics.

Third, the model could be extended by examining additional moderators such as environmental uncertainty, technological turbulence, AI trust, organizational digital maturity, supply chain complexity, or top management support. These variables may determine when emerging digital capabilities generate stronger resilience outcomes.

Fourth, future research could examine other mediating mechanisms, including supply chain visibility, organizational mindfulness, knowledge sharing, information-processing capability, digital agility, or risk management capability. Comparing alternative mechanisms could provide a more comprehensive explanation of how Agentic AI and digital twins generate organizational value.

Fifth, future studies should investigate whether the relationships differ across industries such as manufacturing, retail, pharmaceuticals, automotive, food supply chains, logistics, and technology-intensive sectors. Multi-group analysis could also examine differences according to firm size, level of digital maturity, or degree of AI adoption.

Finally, Agentic AI remains a rapidly emerging area. Future research should investigate new phenomena such as multi-agent supply chain coordination, autonomous procurement agents, agent-to-agent negotiation, AI-generated disruption strategies, algorithmic accountability, and the risks of excessive autonomy. Research examining both the benefits and potential vulnerabilities associated with increasingly autonomous supply chains will become particularly important as agentic technologies mature.

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