When Does AI Capability Pay Off? Absorptive Capacity, Supply Chain Visibility, and Resilience in Construction

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ABSTRACT

This study examines how digital twin adoption influences supply chain performance and supply chain resilience while investigating the mechanisms and boundary conditions underlying these relationships. Specifically, the study examines AI-driven supply chain capability and supply chain visibility as mediators and absorptive capacity as a moderator. A quantitative cross-sectional survey design was employed to collect data from supply chain professionals. A total of 350 questionnaires were distributed, yielding 279 usable responses and a response rate of 79.71%. Measurement scales were adopted and adapted from established previous research. The data were analyzed using ADANCO through partial least squares structural equation modeling to assess reliability, validity, direct effects, mediation, and moderation. The findings demonstrate that digital twin adoption positively influences supply chain performance, supply chain resilience, AI-driven supply chain capability, and supply chain visibility. AI-driven supply chain capability and supply chain visibility significantly enhance both performance and resilience and mediate the relationships between digital twin adoption and the two outcomes. Absorptive capacity positively strengthens the relationships between digital twin adoption and both supply chain performance and resilience. This study extends digital supply chain research by integrating technological, informational, analytical, and knowledge-based capabilities within a unified framework. Drawing on dynamic capability theory, it demonstrates how digital twin adoption generates supply chain benefits through complementary capabilities and under varying levels of absorptive capacity. The findings provide managers with guidance for developing integrated digital transformation strategies.

Keywords: Digital Twin Adoption, AI-Driven Supply Chain Capability, Supply Chain Visibility, Supply Chain Performance, Supply Chain Resilience

INTRODUCTION

The complexity, interdependency, and fragility of supply chains have been exacerbated by demand volatility, geopolitical risks, natural disasters, technological advances and global health crises (Rohan et al., 2025). A boon has been the need for technologies to track processes, predict risks, and make decisions in a timely fashion, as a result of these conditions (Sah & Shaikh, 2025). This is where digital twin technology shines with its potential to build dynamic digital representations of physical supply chain processes and to link operational data with analytical and simulation tools, in real time (Dey et al., 2023; Haddad et al., 2026). These systems enable the monitoring of real-time data, analysis of scenarios, optimization, and proactive decision making, which enhances efficiency and adaptability (Singh et al., 2023; Ye et al., 2025). Data driven decision making is a promising approach to enhancing supply chain visibility and operational optimization, as digital twins are found to offer valuable support in recent studies (Shorif & Islam, 2024).

Empirical studies have shown the positive impact of digital technologies on supply chain outcomes have grown in number. The benefits of digital technologies for supply chain outcomes have been established in an increasing number of studies (Coelho et al., 2024). Adopting the digital twin can enhance supply chain resilience, as evidenced by the ability to predict, simulate, monitor, and plan for disruption recovery (Rashid & Rasheed, 2025; Tennakoon et al., 2023). Likewise, digital twin based simulation has been demonstrated to be a tool for decision makers to assess disruption scenarios and to optimize the resilience related performance indicators (Haddad et al., 2026). Other studies point out that digital twins can enhance the transparency of the supply chain by connecting data from various operational processes and assist in data-based decision-making (Cheng et al., 2024). Also, the research evidence suggests that digital technologies can enhance dynamic capabilities, which help firms sense the environment, capitalize on opportunities and convert assets to adapt to supply chain uncertainty (Liu et al., 2024).

Despite these findings, there are still some gaps in the literature: First, research has focused mostly on a technological and conceptual approach to digital twins, with relatively limited research that has explored how digital twins affect supply chain performance and resilience at the same time. Current research tends to be case-based, industry-specific, and/or scenario-specific, providing limited information on the extent to which use of a digital twin brings wider organizational benefits to a range of supply chain outcomes. While the adoption has been shown to have beneficial impacts on resilience, the mechanisms of how it enhances performance and resilience are not fully understood (Belhadi et al., 2021; Gani & Mithila, 2026). Moreover, previous studies have pointed to the importance of visibility as one of the advantages of digital twins, however, little research has explored the linkage between better visibility and performance and resilience outcomes as a result of technological adoption.

A second gap relates to the limited incorporation of complementary organisational capabilities into digital twin research. Although digital twins can generate extensive and timely information about supply chain operations, technology alone does not ensure improved performance or resilience. In this context, supply chain visibility and AI capability represent theoretically distinct but complementary mechanisms. Visibility refers to the extent to which relevant supply chain information is transparent, accessible, timely, and accurate across activities and partners. It therefore reflects the information transparency enabled by digital technologies and allows organisations to identify what is occurring across the supply chain. In contrast, AI capability concerns an organisation’s ability to analyse, interpret, predict, and transform available information into actionable intelligence and informed decisions (AlMahri et al., 2025; Bowen & Siegler, 2024). Thus, visibility answers what is happening within the supply chain, whereas AI capability helps organisations understand patterns, anticipate future conditions, and determine appropriate responses. A digital twin may therefore enhance visibility by providing a dynamic and integrated representation of supply chain processes, while AI capability determines how effectively the information generated through that representation is analysed and converted into predictive and decision-making value.

Similarly, absorptive capacity may influence whether organisations can acquire, assimilate, transform, and exploit knowledge generated through digital technologies. While previous studies have examined dynamic capabilities and digital supply chain technologies, limited attention has been given to integrated models that distinguish information transparency (visibility), analytical intelligence (AI capability), and knowledge utilisation (absorptive capacity) within the digital twin–supply chain relationship. In particular, insufficient research has examined how digital twin adoption improves supply chain performance and resilience through enhanced visibility and AI-enabled analytical capability, while organisational absorptive capacity may strengthen the ability to exploit these technological and informational resources. This creates a need for an integrated framework that specifies the distinct roles of digital twin adoption, visibility, AI capability, performance, resilience, and absorptive capacity. The present study therefore examines these mediating and moderating mechanisms within a unified framework, addressing an important theoretical and empirical gap in the digital supply chain literature.

The main goal of this study is to examine the effects of digital twin adoption on supply chain performance and supply chain resilience, while investigating the organisational mechanisms through which these effects occur. Accordingly, the study addresses the following research questions:

RQ1: What is the effect of digital twin adoption on supply chain performance and supply chain resilience?
RQ2: To what extent do AI capability and supply chain visibility mediate the relationships between digital twin adoption and supply chain performance and resilience?
RQ3: To what extent does absorptive capacity moderate the relationships between digital twin adoption and supply chain performance and supply chain resilience?

These questions enable the study to develop a comprehensive understanding of how digital twin adoption generates both operational and adaptive benefits within supply chains. The study distinguishes between the direct effects of digital twin adoption and the organisational mechanisms that enable firms to convert digital resources into improved outcomes.

The value of this research lies in the fact that it merges the existing knowledge of technological adoption, operational performance and resilience while also examining the organizational characteristics and abilities needed to transform digital resources into meaningful results. In practice, the results could contribute to the awareness of chain managers that investing in the digital twin of a product needs to be supported by robust analytical capabilities, information visibility and knowledge absorption mechanisms. Lacking the capabilities to interpret and utilize the information generated, however, digital twin implementation can be underutilized. The results can thus help managers to create an integrated digitalisation strategies that increase efficiency and equips them with better preparedness and response to disruption.

The proposed relationships are supported by theory within dynamic capability theory, which focuses on how people in organisations can combine, build and reconfigure their resources to adapt to the environment (Teece et al., 1997). In this context, digital twin adoption is a technological tool that serves to enhance sensing and seizing, with ongoing monitoring, simulation, and data analysis, and AI powered supply chain capability and visibility are tools that transform this capability into better results. In support of the application of dynamic capability theory to technology enabled resilience and performance, existing research has established that technology can boost organizational capabilities to sustain resilience and achieve superior performance (J. O. Bello et al., 2024; Chen et al., 2024). Absorptive capacity is also a type of organizational capacity and is potentially a key factor in the ability to utilize digital knowledge effectively. In this context, the aim of this research is to test the direct relationship, explore the mediating role of AI-driven capability and visibility, and explore the boundary condition of absorptive capacity to provide a more holistic explanation on how the adoption of digital twin enhances the performance and resilience of a supply chain.

LITERATURE REVIEW

Digital Twin Adoption, Supply Chain Performance and Supply Chain Resilience

Digital twin adoption is the implementation and use of virtual representations that fuse real-time operational data with physical supply chain processes for monitoring, simulation, prediction and decision-making (Adade & de Vries, 2024; Korada, 2024). Supply chain performance is the degree of effectiveness and efficiency in the execution of supply chain activities that lead to a desired result, including cost efficiency, delivery reliability, flexibility, quality and responsiveness (Sah & Shaikh, 2025; Swink et al., 2023). Empirical studies show that a digital twin can enhance performance by providing greater process visibility, predictive analysis, identification of bottlenecks and enabling timely resource allocation (Coelho et al., 2024; Rohan et al., 2025). Recent empirical research has shown that the use of a digital twin correlates with better green supply chain performance, and a study in food supply chains has highlighted the benefits of increased operational efficiency as a result of real-time monitoring and predictive decision making (Haddad et al., 2026; Wang et al., 2025). These results indicate that the adoption of technology can lead to better operational results, as they can continually reflect what is actually happening in the business and act accordingly to prevent inefficient situations before they become costly (Arowoiya et al., 2024; Zaid & Jum'a, 2026). Furthermore, from the manufacturing side of the value chain, evidence indicates that digital twins have a strong impact on the outcomes in the supply chain, and supply chain performance was recognized as an important channel for digitalization's broader organizational benefits.

Supply chain resilience represents the capability of a supply chain to anticipate disruptions, absorb their effects, maintain essential operations, recover quickly, and adapt to changing conditions (Sunmola & Apeji, 2024). By offering a real-time view of supply chain operations, early risk detection, and the ability to model scenarios of disruptions before making a response, digital twin adoption can enhance these capabilities (AlMahri et al., 2025). This relationship does have supporting empirical evidence. A survey of 200 manufacturing organisations showed that digital twin technologies had a notable impact on supply chain resilience and recent empirical work in humanitarian supply chains highlighted the role of digital twin technology in driving supply chain resilience through improved digitally enabled supply chain capabilities (Gani & Mithila, 2026).

H1a: Digital Twin Adoption positively influences Supply Chain Performance.
H1b: Digital Twin Adoption positively influences Supply Chain Resilience.

Digital Twin Adoption, AI-driven Supply Chain Capability and Supply Chain Visibility

AI-driven Supply chain Capability is the ability to use AI and sophisticated analytics to handle supply chain data, make forecasts and inform intelligent decision making (Li et al., 2026; Rohan et al., 2025). Strengthening this capability is the adoption of digital twins, which incorporate real-time operating data, simulation and analytical capabilities (Jahangir et al., 2024; Korada, 2024). Recent research has demonstrated that a digital twin can enable the use of AI within the supply chain decision making process, as it can serve as an interface for the exchange of data, knowledge, analytics and operational processes (Alnaser et al., 2024; Hasan & Crawford, 2025). Digital twins also give AI a dynamic context in which it can detect patterns, analyze situations, forecast results and make decisions for timely interventions (Korada, 2024). Empirical evidence thus indicates that digital twins technology is essential to build intelligence in supply chains. Their real-time data integration and simulation capabilities enable companies to tap into the power of AI for predictive, optimising and adaptive decision making (Adade & de Vries, 2024). New research also shows that integration of digital twins can help with intelligent decision support and process transformation. Supply chain visibility is the capability of having complete, timely and accurate information that covers the activities and conditions of the entire supply chain (Dharmapalan et al., 2026; Swink et al., 2023). By connecting data from physical operations into dynamic digital representations, digital twin adoption can improve visibility. Digital twin approaches have been shown to enhance visibility by offering real-time monitoring, data integration and data-driven decision making (2024) (Hu et al., 2023; Rohan et al., 2025). More evidence shows that digital twin enabled systems can enhance tracking and traceability of logistics information and physical supply chain activities (Baycik, 2024). Digital twins then minimize the information gap and bring more full information to managers about the condition of the supply chain.

H1c: Digital Twin Adoption positively influences AI-driven Supply Chain Capability.
H1d: Digital Twin Adoption positively influences Supply Chain Visibility.

AI-driven Supply Chain Capability, Supply Chain Performance and Supply Chain Resilience

AI-driven Supply Chain Capability is the ability to use Artificial Intelligence (AI) to forecast, optimise, automate, and make data-driven decisions regarding the supply chain. This can help to optimize operations and boost performance, responsiveness and decision accuracy (Wu et al., 2024; Zaid & Jum'a, 2026). Empirical studies demonstrate that the application of AI has a significant impact on supply chain performance, by enhancing information processing and operational decision making (Belhadi et al., 2021). Likewise, the findings from companies reveal that AI in the supply chain contributes to both resilience and performance (Khan et al., 2024). The AI-powered features enable companies to analyse intricate data quickly, predict demand and supply trends, streamline resources and minimize inefficiencies (Nitin, 2025). The enhancements can boost delivery reliability, flexibility, cost efficiency and responsiveness. Empirical evidence also suggests that the use of AI can enhance operational efficiency, which in turn has the potential to positively impact supply chain results (Haddad et al., 2026).

The AI-driven supply chain capability is the ability to leverage intelligent technologies to address uncertainty, detect risks and facilitate adaptive supply chain decisions (Shorif & Islam, 2024; Xu et al., 2025). These capabilities can help build resilience because they give companies a heads up on issues and help them to plan for them. The empirical findings show that AI has a significant positive effect on supply chain resilience, particularly in terms of transparency, operational efficiency, and adaptability (Cheng et al., 2024; Ye et al., 2025). AI features can also enable ongoing learning, predictive analysis and reconfiguration in the event of supply changes. The study, which surveyed 287 executives across the supply chain, identified three organizational processes as the means by which AI enhances supply chain resilience, namely leveraging technology, responding to change and optimizing processes and operations (Liu et al., 2024; Sheikh & Sajja, 2026; Wang et al., 2025). AI's value as a supply chain resilience tool comes through three organizational processes: using technology, adapting to change, and optimizing processes and operations, the research found.

H2a: AI-driven supply chain capability positively influences supply chain performance.
H2b: AI-driven supply chain capability positively influences supply chain resilience.

Supply Chain Visibility, Supply Chain Performance and Supply Chain Resilience

Supply chain visibility is the access to timely, accurate, and relevant supply chain activities, resources and conditions in supply chain networks (Bowen & Siegler, 2024; Dharmapalan et al., 2026). Increased visibility allows organisations to keep track of operations, detect deviations, coordinate activities, and make informed decisions (Yang et al., 2024). Practical evidence shows that visibility positively affects the outcome of the supply chain, as it provides better information and coordination (AlMahri et al., 2025). The research done among manufacturing companies shows that one of the important mechanisms that supply chain digitalization brings to the performance is visibility (Sunmola & Apeji, 2024). Better visibility can help boost performance by minimizing information asymmetry, aiding in demand and inventory management, and speeding up the response to operations changes (Khan et al., 2024). There is also some evidence that visibility is related to performance via better supply chain capacities and resilience, and that this effect is different in various contexts (Swink et al., 2023). Supply chain visibility is the ability of the companies to access information about the activities and conditions in the supply chain (Sunmola & Apeji, 2024). A timely passing of information is especially significant for resilience since firms can use that information to know what risks are coming up and take action before there is a disruption (Bowen & Siegler, 2024). The authors of the study conducted empirical research that revealed how visibility within the supply chain positively impacts the resilience and overall ability of Chinese manufacturing firms. The visibility is a means to strengthen resilience by enhancing the risk identification, monitoring of disruption, coordination, and response capabilities (Wu et al., 2024). Empirical evidence also points to a positive correlation between visibility and supply chain cyber resilience, which shows how information that is accessible can aid in an organisation's response to threats in the wake of disruption (Wang et al., 2025).

H3a: Supply chain visibility positively influences supply chain performance.
H3b: Supply chain visibility positively influences supply chain resilience.

AI-driven Supply Chain Capability as Mediator

AI-driven supply chain capability is the ability to use artificial intelligence and advanced analytics for prediction, optimization and intelligent decision making (Rohan et al., 2025). By employing the digital twin, real time data and simulation environments can be created that enables the analysis using AI and thus allows companies to turn operational information into operational intelligence (Sah & Shaikh, 2025). Recent studies have shown that digital twins can incorporate data, analytics, and decision making processes, and that artificial intelligence enhances predictive and optimization capabilities (Sheikh & Sajja, 2026). The potential for AI to enhance supply chain performance is also evident in empirical studies, which highlight its ability to boost efficiency and decision-making in supply chains (Wu et al., 2024). AI-powered capability in supply chains can also be a crucial means by which digital twin implementation improves resilience (Rohan et al., 2025; Wu et al., 2024). With digital twins, we can continuously monitor and simulate various scenarios, and AI can analyse the trends that are emerging, predict the possible disruptions and help to respond quickly (Belhadi et al., 2021). Studies show that digital twins play a role in resilience by synchronizing data in real time, analyzing disruptions and making adaptable decisions (Belhadi et al., 2021). Likewise, empirical studies have shown that the capabilities of AI enhance resilience through predictive and adaptive responses to uncertainty. So, the sole use of digital twin does not necessarily lead to resilience benefits if organizations lack the capacity of AI to interpret and take action from information continuously generated (Dey et al., 2023; Zaid & Jum'a, 2026). Predictive insights and adaptive responses can be enabled by using AI driven capability to turn digital twin data into insights, which will boost resilience.

H4a: AI-driven supply chain capability mediates the positive relationship between digital twin adoption and supply chain performance.
H4b: AI-driven supply chain capability mediates the positive relationship between digital twin adoption and supply chain resilience.

Supply Chain Visibility as Mediator

Chain visibility allows companies to get information about what is happening in the chain in real time and with accuracy, which is a key mechanism for the operational benefits of digital technologies (Dharmapalan et al., 2026). Digital twin implementation can improve visibility by combining real-time data and can create dynamic visuals of interdependent supply chain processes. Empirical studies have substantiated that the use of digital twin solutions enhances visibility and aids in data-informed decision making (Yang et al., 2024). Improved visibility can then help to improve supply chain performance through coordination, quick decision making, identification of disruptions, and optimization of resources (AlMahri et al., 2025). The study demonstrates the mediating effect of visibility between supply chain digitalization and performance, based on empirical evidence, which validates the role of visibility as a transmission mechanism (Hu et al., 2023). Thus, digital twin use is likely to enhance the performance partly through the increased visibility of the supply chain (Khan et al., 2024). How digital technologies help to build resilience can be further explained through supply chain visibility and knowing when things are going wrong or when vulnerabilities arise, and being able to monitor and coordinate appropriate responses. Digital twin systems help increase visibility by integrating operational data and offering real-time visibility of supply chain conditions (Bowen & Siegler, 2024).

H5a: Supply chain visibility mediates the positive relationship between digital twin adoption and supply chain performance.
H5b: Supply chain visibility mediates the positive relationship between digital twin adoption and supply chain resilience.

Absorptive Capacity as Moderator

Absorptive capacity is the capacity of organizations to acquire, assimilate, transform and exploit external knowledge for organizational use. It can enhance the value delivered by the use of digital technologies as organisations with higher absorptive capacity would be better able to assimilate new information and turn technological resources into operational gains (Signorini & Pomè, 2025). Empirical evidence shows that absorptive capacity is positively associated with digital capability and supply chain innovation performance, and therefore plays a crucial role in using digital resources to achieve organizational benefits (Arowoiya et al., 2024). The research on supply chain digitalization also reveals that absorptive capability is linked to the ability of the firms to process information and adapt to it to achieve better performance (A. O. Bello et al., 2024). Therefore, companies with a higher absorptive capacity will be better positioned to take advantage of the information and analytical opportunities created by the use of digital twin (Xu et al., 2025). Thus, the benefits of the use of digital twins in supply chains should increase with absorptive capacity. Absorptive capacity also gives firms the ability to identify the new knowledge they need to recognize, to understand the information that indicates disruption, and to take the necessary action (Korada, 2024). Empirical evidence indicates that absorptive capacity is a key factor that improves the resilience of supply chain because it facilitates organizational learning, adaptation and external information use (Javaid et al., 2025). Likewise, absorptive capacity was linked to a supply chain's visibility and cyber resilience, suggesting that companies that have more absorptive capacity will gain more resilience benefits from digital information.

H6a: Absorptive capacity positively moderates the relationship between digital twin adoption and supply chain performance, such that the relationship is stronger at higher levels of absorptive capacity.
H6b: Absorptive capacity positively moderates the relationship between digital twin adoption and supply chain resilience, such that the relationship is stronger at higher levels of absorptive capacity.

Theoretical Framework Supporting the Research

Dynamic capability theory provides the theoretical foundation for the relationships suggested in this research, since it is concerned with the way firms develop, combine, and reconfigure resources and capabilities to respond to shifts in the business environment and to maintain performance. The differences between dynamic capability theory and a static resource based view are that the former focuses on the logic behind how an organisation senses and recognises change and how it is able to make change happen in order to make its technological resources valuable (Teece et al., 1997). The sense, seize, and transform logic here is not directly measured processes, but an interpretation. In this context, the use of digital twin is considered as a digital resource and organisational practice that continuously collects the operational data, simulates scenarios, monitors conditions of the supply chain, and enables timely managerial interventions, but not as a kind of dynamic capability. Recent research has revealed that digitalisation can augment the resilience and performance of the supply chain through dynamic capabilities, including absorptive, response and recovery (Yang et al., 2024). In the proposed framework, it is therefore expected that the adoption of digital twin will enhance the performance and resilience of the supply chain mainly through the dynamic capabilities that the digital resource will bring to reinforce the supply chain capability and supply chain visibility, that is, the contribution of the digital resource to the value of the supply chain. The combination of AI enabled capability with the information generated by the digital twin provides the organisation with predictive insights, optimisation, and intelligent decision-making; and visibility provides the organisation with the ability to detect changes, risks and disruptions throughout supply chain activities. These are the capacities that comprise the process through which the technological resource is converted to better performance and resilience results. The framework also includes absorptive capacity as a boundary condition because the absorptive capacity of the organisations differ in their ability to acquire, assimilate, transform and exploit new knowledge and technological information. Organisations with greater absorptive capacity are likely to benefit more from the adoption of a digital twin as they will be more able to understand the information produced by a digital twin and put it into practice for operations and resilience. This aligns with the body of evidence showing that the absorptive capacity is key to the relationship between digitalisation and SC performance and resilience (Hu et al., 2023). The proposed relationships and theory are depicted in Figure 1.

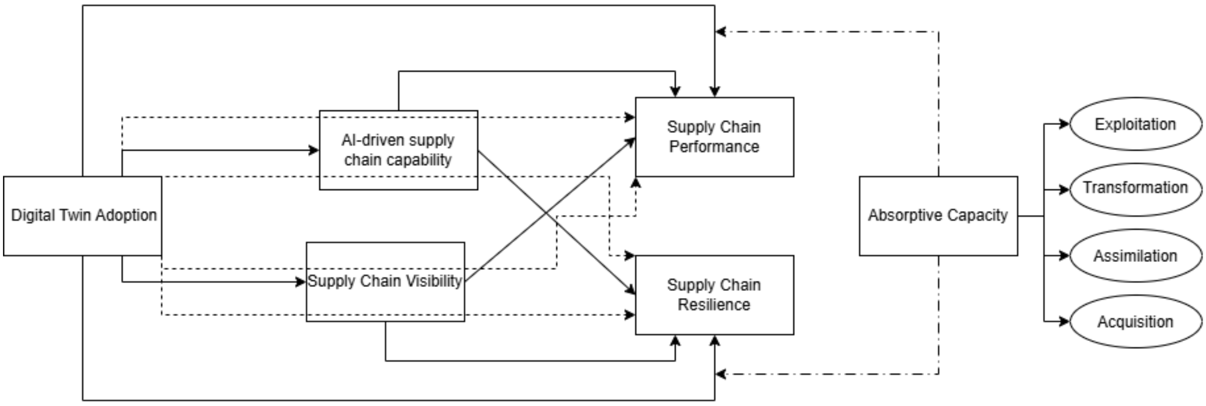

Figure 1: Conceptual Framework

METHODOLOGY

Research design

The research design was quantitative and cross-sectional, which was used to analyze the relationship between digital twin adoption, the capability of using AI in the supply chain, and supply chain visibility, supply chain performance, supply chain resilience, and absorptive capacity. A quantitative approach was appropriate because the study was to statistically test theoretically developed hypotheses and to investigate direct, mediating and moderating relationships among latent variables. The cross-sectional design allowed for obtaining data from professionals in the supply chain at a given point in time. It is common in empirical supply chain research to use survey-based designs, which enable researchers to gain insight into the perceptions of the organizations they are studying and assess relationships between technological and organizational capabilities (Hair et al., 2019).

Population, sample and data collection

The target population included managers and professionals who work in the supply chain related functions such as procurement, purchasing, production, logistics, transportation, warehousing, distribution, inventory management, and supply chain management. The respondents were selected because they have practical knowledge of the supply chain and have a better understanding of implementation and organizational implications of the digital technologies. A structured questionnaire was used to collect primary data. 350 questionnaires were sent out and 279 usable questionnaires were returned (79.71%). The questionnaires were sent via the Internet, as well as via direct survey, to respondents who had relevant jobs in the supply chain. Online questionnaires were distributed via professional networks and electronic communications and printed questionnaires were sent directly to the eligible respondents in organizations. The survey was conducted on a voluntary basis, and the respondents were given the info that the questionnaire will be utilized for academic research. The application of trained organizational respondents conforms to the previous study on digital technologies, the supply chain capabilities, and organizational resilience.

Measurement

Constructs used in the study were drawn from previous studies to ensure that they were reliable and valid. The level of adoption of digital twins was assessed by using 5 items adapted from previous digital twin research (Singh et al., 2026). AI-driven Supply Chain Capability was measured with 5 items adapted from (Dubey et al., 2021) and Supply Chain Visibility was measured with 5 items adapted from (Huang et al., 2023). The performance of the supply chain was also assessed using the 7 items adapted from (Wang & Pan, 2022) and the resilience of the supply chain was assessed using 4 items adapted from (Issa et al., 2024). Absorptive capacity was measured using four dimensions based on (Flatten et al., 2011) namely acquisition (3 items), assimilation (4 items), transformation (4 items) and exploitation (3 items). All measurement items were modified in keeping with the conceptual meaning of the original scales, but to be meaningful for the present study. All items were measured using 5-point Likert scale.

Data analysis

Data collected were analyzed by partial least squares structural equation modeling (PLS-SEM) using ADANCO software. This was suitable because the proposed framework contained multiple latent constructs, as well as direct, mediation, and moderation relationships (Hair & Alamer, 2022). This analysis was conducted in two steps. The assessment of the measurement model was first conducted to ensure reliability and validity. Cronbach's alpha, Jöreskog's rho, and Dijkstra-Henseler's rho were used to examine the internal consistency. The convergent and discriminant validity was determined by the indicator loadings, average variance extracted, and heterotrait-monotrait ratio (Henseler et al., 2014), respectively. Second, the structural model was evaluated to verify the hypotheses proposed. As recommended by PLS-SEM ((Preacher & Hayes, 2008), the significance of direct effect, indirect effect, and interaction effect were determined by Bootstrap. Lastly, R^2 was used to determine how well the model explained the data, Q^2 to determine how well the model was predictive of the data, and SRMR to measure the model fit.

RESULTS

Results of the reliability and convergent validity of all constructs are reported in Table 1. Dijkstra-Henseler's rho, Jöreskog's rho, and Cronbach's alpha values are between 0.820 and 0.935, which are above the recommended value of 0.70, indicating good internal consistency. The reliability of digital twins is also quite high, with rhos of 0.870, 0.866 and alpha of 0.867, and the reliability of AI-based supply chain capability reports is similar at 0.872, 0.864 and 0.865. The supply chain visibility, supply chain performance and supply chain resilience also have very good reliability with an alpha value of 0.893, 0.931 and 0.882, respectively. The four dimensions of absorptive capacity also meet the criterion of reliability, (alpha value range of 0.820 to 0.870). Moreover, the AVE values vary from 0.562 to 0.678, which is higher than the recommended value of 0.50. As such, all constructs account for over 50% of the variance in their respective indicators, and thus showed good convergent validity.

Table 1: Variables reliability and validity

Construct	Dijkstra-Henseler's rho (ρA)	Jöreskog's rho (ρc)	Cronbach's alpha(α)	AVE
Digital Twin Adoption	0.870	0.866	0.867	0.565
AI-driven Supply Chain Capability	0.872	0.864	0.865	0.562
Supply Chain Visibility	0.895	0.893	0.893	0.625
Supply Chain Performance	0.935	0.931	0.931	0.659
Supply Chain Resilience	0.886	0.882	0.882	0.652
Acquisition	0.865	0.863	0.863	0.678
Assimilation	0.873	0.870	0.870	0.626
Transformation	0.863	0.860	0.859	0.606
Exploitation	0.833	0.821	0.820	0.607

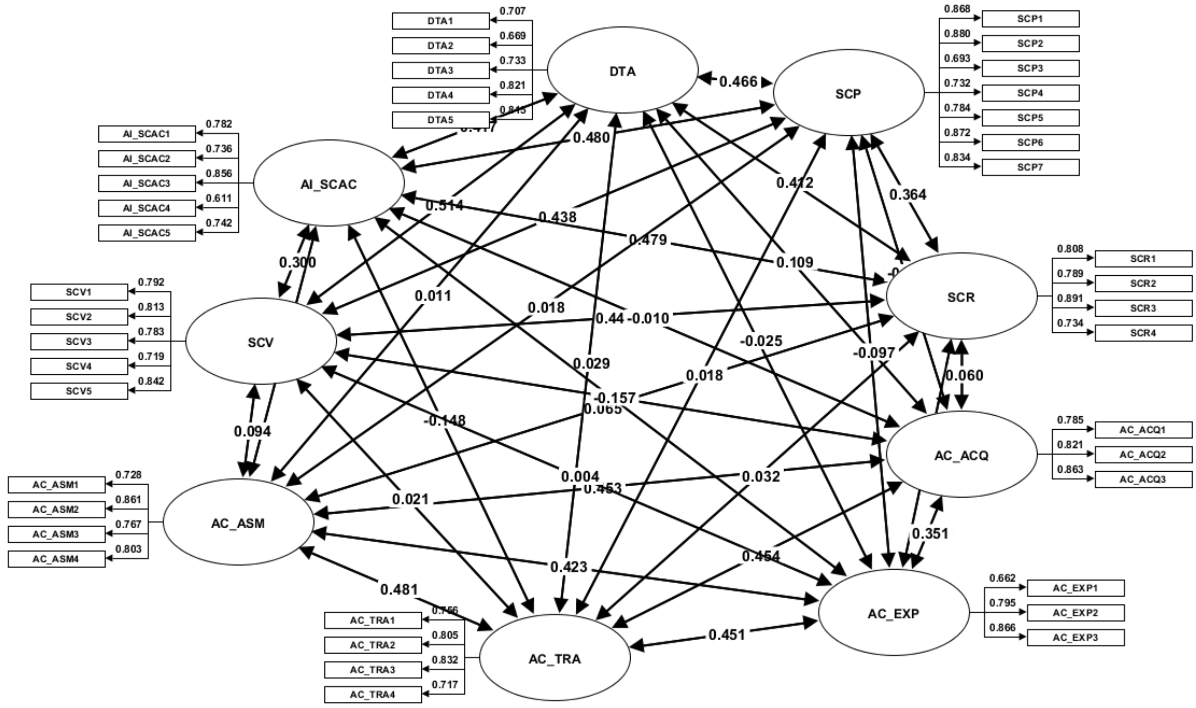

Figure 2: Estimated Model

Table 2 and Figure 2 report the indicator loadings. The loadings range from 0.611 to 0.891, indicating that the indicators generally demonstrate adequate associations with their respective constructs. For digital twin adoption, loadings range from 0.669 to 0.821. AI-driven supply chain capability shows loadings between 0.611 and 0.856, while supply chain visibility ranges from 0.719 to 0.842. Supply chain performance records loadings from 0.693 to 0.880, and supply chain resilience ranges from 0.734 to 0.891. The absorptive capacity dimensions also demonstrate satisfactory loadings, ranging from 0.662 to 0.863. Although some indicators have comparatively lower loadings, they remain above the commonly accepted minimum level of 0.60. Therefore, the CFA results support the adequacy of the measurement model.

Table 2: Confirmatory Factor Analysis

Indicator	Digital Twin Adoption	AI-driven Supply Chain Capability	Supply Chain Visibility	Supply Chain Performance	Supply Chain Resilience	Acquisition	Assimilation	Transformation	Exploitation
DTA1	0.707								
DTA2	0.669								
DTA3	0.733								
DTA4	0.821								
DTA5	0.815								
AI_SCAC1		0.782							
AI_SCAC2		0.736							
AI_SCAC3		0.856							
AI_SCAC4		0.611							
AI_SCAC5		0.742							
SCV1			0.792						
SCV2			0.813						
SCV3			0.783						
SCV4			0.719						
SCV5			0.842						
SCP1				0.868					
SCP2				0.880					
SCP3				0.693					
SCP4				0.732					
SCP5				0.784					
SCP6				0.872					
SCP7				0.834					
SCR1					0.808				
SCR2					0.789				
SCR3					0.891				
SCR4					0.734				
ACQ1						0.785			
ACQ2						0.821			
ACQ3						0.863			
ASM1							0.728		
ASM2							0.861		
ASM3							0.767		
ASM4							0.803		
TRA1								0.756	
TRA2								0.805	
TRA3								0.832	
TRA4								0.717	
EXP1									0.662
EXP2									0.795
EXP3									0.866

Discriminant validity (HTMT) is shown in Table 3. All the HTMT ratios are well below the conservative threshold of 0.85, with the highest ratio between digital twin adoption and supply chain visibility at 0.511. The HTMT ratios between digital twin adoption and AI driven supply chain capability, supply chain performance, and supply chain resilience are also well below the recommended threshold. Likewise, the HTMT ratios among the acquisition, assimilation, transformation, and exploitation dimensions remain low. Based on these results, it can be concluded that the constructs are empirically distinct and measure different concepts, indicating that the measurement model has acceptable discriminant validity.

Table 3: Discriminant Validity (HTMT)

Construct	DTA	AI_SCAC	SCV	SCP	SCR	ACQ	ASM	TRA	EXP
Digital Twin Adoption									
AI-driven Supply Chain Capability	0.413								
Supply Chain Visibility	0.511	0.299							
Supply Chain Performance	0.465	0.476	0.436						
Supply Chain Resilience	0.407	0.477	0.446	0.360					
Acquisition	0.110	0.012	0.119	0.068	0.062				
Assimilation	0.015	0.042	0.094	0.019	0.062	0.453			
Transformation	0.027	0.149	0.022	0.019	0.030	0.455	0.479		
Exploitation	0.024	0.161	0.001	0.098	0.027	0.349	0.421	0.451	

The explanatory and predictive power of the structural model is presented in Table 4. The R^2 values for AI-driven supply chain capability, supply chain visibility, supply chain performance and supply chain resilience are 0.174, 0.265, 0.357 and 0.346 respectively. Therefore, the model accounts for 17.4% of the variance in the AI-driven supply chain capability, 26.5% in supply chain visibility, 35.7% in supply chain performance and 34.6% in supply chain resilience. All the Q^2 values are above 0.1 showing predictive relevance, with the values ranging from 0.161 to 0.338. The SRMR value of 0.061 is within an acceptable range of model fit.

Table 4: R-square statistics Model Goodness of Fit Statistics

Construct	R2	Adjusted R2	Q^2	RMSE	MSE	SRMR
AI-driven Supply Chain Capability	0.174	0.171	0.161	0.741	0.549	0.061
Supply Chain Visibility	0.265	0.262	0.249	0.707	0.500	
Supply Chain Performance	0.357	0.347	0.338	0.649	0.421	
Supply Chain Resilience	0.346	0.336	0.327	0.658	0.433	

The relationships between the study variables were estimated using path analysis and are shown in Figure 3, with the results reported in Table 5 using a one tailed test since all hypotheses are directional. Digital twin adoption has a positive effect on supply chain performance (β = 0.214, t = 2.687, p = 0.004), supporting H1a. Digital twin adoption also has a positive and significant effect on supply chain resilience (β = 0.121, t = 1.952, p = 0.026), supporting H1b. Digital twin adoption strongly predicts AI driven supply chain capability (β = 0.417, t = 7.471, p < 0.001) and supply chain visibility (β = 0.515, t = 9.161, p < 0.001), supporting H1c and H1d. AI driven supply chain capability significantly influences performance (β = 0.318, t = 4.946, p < 0.001) and resilience (β = 0.354, t = 5.436, p < 0.001), supporting H2a and H2b. Likewise, supply chain visibility positively predicts performance (β = 0.235, t = 3.543, p < 0.001) and resilience (β = 0.274, t = 3.976, p < 0.001), supporting H3a and H3b. The indirect path via AI driven supply chain capability is significant for both performance (β = 0.133, p < 0.001) and resilience (β = 0.148, p < 0.001), validating H4a and H4b. Supply chain visibility also mediates the relationship significantly for performance (β = 0.121, p < 0.001) and resilience (β = 0.141, p < 0.001), supporting H5a and H5b. Last, the interaction between digital twin adoption and absorptive capacity is positively and significantly related to performance (β = 0.142, t = 2.679, p = 0.004) and to resilience (β = 0.157, t = 2.849, p = 0.002), supporting H6a and H6b. Overall, all the hypothesized relationships are supported by the empirical evidence.

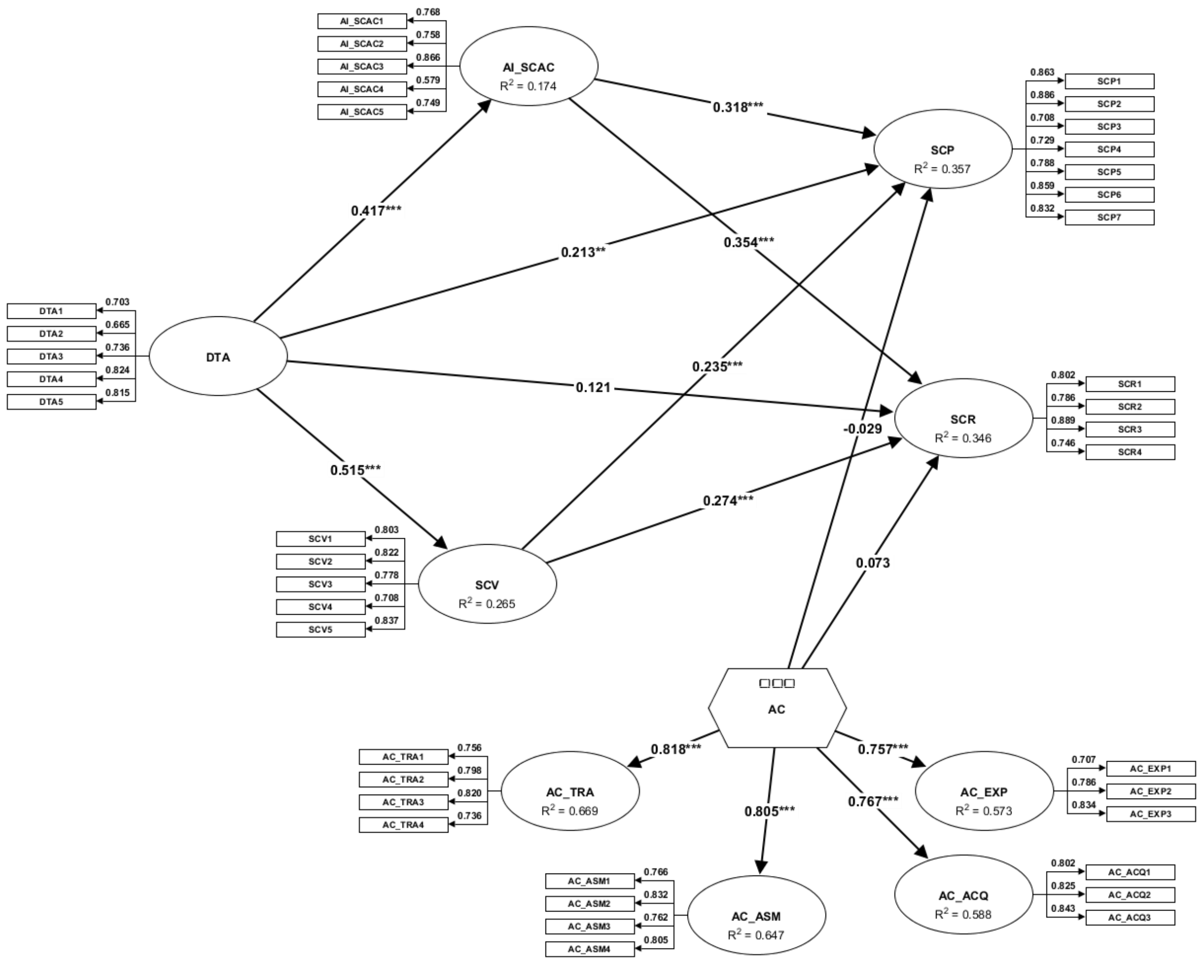

Figure 3: Structural Model for Path Analysis

Table 5: Path Analysis

	beta	SE	t-value	p-value	2.50%	97.50%
DTA -> SCP	0.214	0.080	2.687	0.004	0.050	0.378
DTA -> SCR	0.121	0.062	1.952	0.026	0.025	0.261
DTA -> AI_SCAC	0.417	0.056	7.471	p<.001	0.301	0.527
DTA -> SCV	0.515	0.056	9.161	p<.001	0.397	0.619
AI_SCAC -> SCP	0.318	0.064	4.946	p<.001	0.189	0.449
AI_SCAC -> SCR	0.354	0.065	5.436	p<.001	0.223	0.473
SCV -> SCP	0.235	0.066	3.543	p<.001	0.102	0.370
SCV -> SCR	0.274	0.069	3.976	p<.001	0.141	0.414
DTA → AISCAC → SCP	0.133	0.030	4.408	p<.001	0.030	0.152
DTA → AISCAC → SCR	0.148	0.033	4.451	p<.001	0.036	0.162
DTA → SCV → SCP	0.121	0.028	4.312	p<.001	0.059	0.209
DTA → SCV → SCR	0.141	0.031	4.531	p<.001	0.051	0.195
DTA × AC → SCP	0.142	0.053	2.679	0.004	0.032	0.252
DTA × AC → SCR	0.157	0.055	2.849	0.002	0.043	0.271

Note. All hypotheses are directional; significance was assessed using a one tailed test supported when one tailed $p < 0.05$ and the CI excludes zero).

DISCUSSION

The findings show that digital twin use is a more than a technology investment; It is a strategic capability that has the potential to change the way supply chains process information, make decisions, coordinate activities, and react to uncertainty. Supply chains are becoming more complex, more connected, and more vulnerable, requiring organizations to have the ability to anticipate change in the environment—before vulnerabilities grow into significant disruptions. The empirical results explain the benefits of digital twin adoption for supply chain performance and resilience and for the capability of AI supply chains and supply chain visibility.

The results suggest that the use of digital twins has a positive effect on the performance of the supply chain. This connection implies that digital twins have the potential to enhance operational coordination, planning, resource utilization, monitoring, and management decision making. The finding is in line with the dynamic capability perspective that suggests that firms outperform the rest of the market by organizing their resources to adapt to changes in their environment (Teece et al., 1997). Digital twins offer real-time, dynamic simulations of supply chain activities, allowing managers to track and analyze operations, and test out different scenarios before making decisions. Previous research also shows that digital twins contribute to enhancing the performance and sustainability of the supply chain, especially when supported by organizational resilience capabilities (Coelho et al., 2024). Thus, digital twins must be viewed as more than just monitoring solutions – they are tools to support decision-making and reconfiguration of operations.

The findings also support the hypothesis that using a digital twin will be positively correlated with supply chain resilience. This discovery means that digital twins can go beyond reactive and proactive disruption management. Digital twins can be used to continuously integrate, simulate, and analyse various scenarios to help organizations understand vulnerabilities and devise suitable responses before disruptions have a major impact on operations (A. O. Bello et al., 2024). This discovery aligns with prior studies that demonstrate the benefits of digital twin technologies in enhancing supply chain resilience through better preparedness, coordination, and strategic alignment for disruptions (Coelho et al., 2024). The digital twin, in the context of dynamic capability theory, enhances the firm's capacity to detect the environment's threats, to respond in an appropriate manner, and to adapt the resources based on the changing environment. So, digital twins are not just a tool for optimizing operations, they are also a enabler for organizational adaptiveness and disruption-management.

The results also indicate that the use of the digital twin has a positive impact on the capability of the AI toolset in the supply chain and the visibility of the supply chain. Digital twins link physical activities in the supply chain to their digital twin, leading to fewer information gaps between complex interlinked activities. The value of visibility is that it helps organizations keep track of activities, detect vulnerabilities, and address uncertainty. This finding aligns with studies indicating that chain visibility enhances resilience, as better risk identification and adaptive response to changes lead to more effective outcomes (Korada, 2024). Likewise, the positive correlation with AI capability suggests that the digital twin environment will offer the necessary data and simulation tools to enable prediction, optimization, and intelligent decision-making. AI has proven to enhance the performance and resilience of supply chains by leveraging its analytical and adaptive capabilities (Alnaser et al., 2024). The conclusions support the dynamic capability theory as the value of technological resources is enhanced by complementary organizational resources.

The mediation results also further reinforce that capability in the supply chain and supply chain visibility are key enablers of digital twin adoption to positively impact supply chain outcomes. The key indirect relationships illustrate how digital twins impact performance and resilience, both directly, and also by enabling the organization to better understand and keep up with the supply chain. This result, from a dynamic capability point of view, highlights the processes by which technological resources are converted into organizational outcomes (sensing, seizing, reconfiguring) (Signorini & Pomè, 2025). While AI-driven capability can turn digitally created information into predictive and intelligent decisions, visibility can help organizations identify changes in the various activities of the interconnected supply chain. This interpretation aligns with earlier studies that have linked digital capability, digital agility, digital resilience and digital absorptive capacity as mechanisms that enable innovation and digital resilience.

Lastly, the results confirm the moderating effect of absorptive capacity on the relationship between the adoption of digital twin and the performance and resilience of the supply chain. Digital twin adoption yields more benefits to organisations that are better at acquiring, assimilating, transforming and exploiting knowledge (Adade & de Vries, 2024). The absorptive capacity of an organization is what differentiates between those that can understand digitally-created information, assimilate it with existing knowledge, and use it in decision-making for operations and disruption. This is in line with the dynamic capability theory which holds that organizational capacities in the transformation of knowledge and resources into valuable actions is an important factor. Previous studies also show that there is a positive relationship between absorptive capacity and digital capability, supply chain agility, resilience, and innovation performance (Rohan et al., 2025).

In summary, the results provide a picture of digital transformation as an interrelated system that encompasses technology, information, intelligence, and organizational learning. The adoption of digital twin equips the technological backbone, while the intelligence of AI-driven capability transforms data into meaningful intelligence and visibility of supply chain enhances situational awareness, and the absorptive capacity facilitates the transformation of knowledge into action. All these capabilities work in concert to enhance the supply chain performance and resilience. The results thus contribute to the theory of dynamic capabilities by showing that the adoption of advanced technologies is not a sufficient condition to guarantee the sustainable achievement of organizational outcomes, but also the development of complementary capabilities is required to perceive the environmental changes, to seize opportunities, and to reconfigure resources.

Implications

Theoretical Implications

This research advances the dynamic capability theory by proving digital twin implementation can be considered a technological capability that can enhance the performance and resilience of a supply chain by complementing other organizational capabilities. The results complement the theoretical view as they identify the capability of the supply chain enabled by AI, and its visibility as key mechanisms that bridge the digital twin adoption to better supply chain results. This indicates that technological resources are not enough; their value is in the organisations capacity to process information, produce intelligence, and to be aware of what is going on in the supply chain. The study also enriches the dynamic capability theory by setting the absorptive capacity as a boundary condition that further enhances the advantages of digital twin adoption. The study offers a more complete understanding of the interrelationship between technological and knowledge-based capabilities and the advantages they create in organizations in that it incorporates direct, mediating and moderating relationships in one package. The results enlarge the current theoretical knowledge about the application of digital transformation in supply chain management.

Practical Implications

The results have significant implications for supply chain managers and organizational decision makers looking to enhance the performance and resilience of their operations through digital transformation. Digital twin adoption demands a strategic investment and cannot be treated as just a technology, as it requires certain complementary capabilities to achieve benefits. The organization needs to build analytical capabilities based on AI to transform real-time digital data into future-oriented insights and decision-making. There's also a need to invest in systems that integrate data and share information, enhancing visibility in the supply chain and facilitating the real-time detection of operational issues and disruptions. Managers should also increase the ability of their employees to receive, interpret, convert and utilize new knowledge they gain with the use of digital technologies, by building absorptive capacity. This can be done with training, knowledge sharing, and cross functional working. This study also shows that organisations need to adopt integrated approach between digital twin and supply chain processes and decision systems to harness the greatest value contribution of digital twin to performance improvement and enhancing resilience.

LIMITATIONS AND FUTURE DIRECTIONS

This study has several limitations that present opportunities for future research studies. The cross-sectional design restricts the capacity to establish causal connections and to obtain information on the evolution of the use of digital twins over time. Longitudinal studies in the future could be used to examine how Digital twin capability will evolve and how this will impact the supply chain. Survey data also was used in the study that could skew perception. Objective organizational performance data and qualitative evidence could be included in future research. In addition, selected mediating and moderating mechanisms were highlighted in the model. Other capacities like organizational agility, digital maturity, technological readiness or innovation capability could be explored in future research. Analyses of how well the results can be generalized across industries and countries could be strengthened by comparative studies.

CONCLUSION

The findings of this study indicate that digital twin adoption is a valuable technological capability to enhance the performance and resiliency of the supply chain. The results show that its benefits are not limited to the operational gains: the digital twin adoption has also been associated with an increase in the capacity of AI to support the supply chain, and with supply chain visibility, which in turn have improved the supply chain outcomes. The mediation effects validate the value that organizations can gain from digital twins, as they can turn digitally produced data into intelligent decisions and have good visibility of all supply chain activities. The moderating results also highlight the role of organizational knowledge capacities in digital transformation, as absorptive capacity enhances the positive effects of digital twin implementation. The study thus offers a comprehensive understanding of the joint effects of technological resources and organizational capabilities on creating supply chain benefits. The research builds on the theories of Dynamic Capability, adding to the theoretical and practical knowledge of how organizations can utilize a digital twin to create more efficient, informed, adaptive, and resilient supply chains.

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