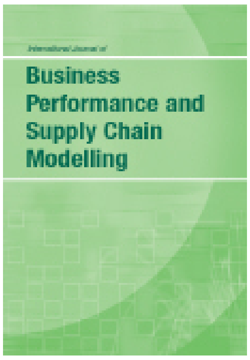

International Journal of Business Performance and Supply Chain Modelling

ISSN online: 1758-941X - ISSN print: 1758-9401
https://www.inderscience.com/ijbpscm

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Darjat Sudrajat, Adesatya Lentera Nagari, Dony Apriyanto

DOI: 10.1504/IJBPSCM.2026.10080760

Article History:

Received:	15 February 2025
Last revised:	06 March 2026
Accepted:	13 March 2026
Published online:	01 September 2026

Investigating the impact of AI and big data capabilities on supply chain performance: the mediating role of agility and resilience

Darjat Sudrajat*, Adesatya Lentera Nagari, and Dony Apriyanto

Management Department,
BINUS Business School Master Program,
Bina Nusantara University,
Jakarta, 10270, Indonesia
Email: sudrajatd@binus.ac.id
Email: adesatya.nagari@binus.ac.id
Email: dony.apriyanto@binus.ac.id
*Corresponding author

Abstract: This study investigates the impact of artificial intelligence (AI) and big data capabilities on supply chain performance through the mediating roles of supply chain agility and resilience. Based on the dynamic capabilities view, it explains how digital technologies generate value by enabling organisations to adapt to and manage disruptions effectively. A cross-sectional survey of employees from logistics service providers in Indonesia was conducted, and 286 responses were obtained for analysis. Data were analysed through partial least squares structural equation modelling (PLS-SEM). The findings demonstrate that AI and big data capabilities amplify supply chain agility, thereby reinforcing resilience and improving supply chain performance. Agility and resilience drive sustained performance under disruption. This study advances theory on dynamic capabilities in supply chain management from an empirical context of an emerging economy and provides managerial implications for logistics managers and policymakers to foster resilient, data-driven supply chains.

Keywords: artificial intelligence; BDA; big data analytics; SCA; supply chain agility; SCR; supply chain resilience; supply chain performance.

Reference to this paper should be made as follows: Sudrajat, D., Nagari, A.L. and Apriyanto, D. (2026) 'Investigating the impact of AI and big data capabilities on supply chain performance: the mediating role of agility and resilience', *Int. J. Business Performance and Supply Chain Modelling*, Vol. 16, No. 5, pp.1–26.

Biographical notes: Darjat Sudrajat is an Associate Professor at BINUS Business School, BINUS University. He has published 52 SCOPUS-Indexed papers in international journals and proceedings. He has been lecturing at BINUS University for 26 years. Before joining BINUS University as a Structural Faculty Member in 2018, he held managerial roles at several companies for 20 years. He earned a Bachelor's degree in Production Management, a Master's degree in Business Administration and Technology, and a Doctoral degree in Management Science. He also earned international certifications, including a Certified Supply Chain Analyst (CSCA), Certified Supply Chain Manager (CSCM), and Certified Professional in Logistics Management (CPLM) from ISCEA-USA. He has been active in several organisations, including the Indonesian Co-operative Council (DEKOPIN), the Indonesian Chamber of Commerce and Industry (KADIN), Indonesia Logistics Association (ALI), and the Industrial Engineering and Operations Management (IEOM) Society International.

Adesatya Lentera Nagari has an academic background in Logistics Engineering and Supply Chain Management and is experienced in delivering technical and application-based solutions for industrial equipment, such as electric motors, gearboxes, couplings, and MRO components, across sectors including mining, palm oil, cement, and chemical industries. He is skilled in market development, customer relationship management, technical consulting, pricing negotiations, project execution, warehouse operations, and export-import logistics, as well as analysing production flow data to inform critical decisions on MRP implementation and HSE initiatives. He holds international certifications in supply chain management, occupational safety, and Lean Six Sigma.

Dony Apriyanto has more than 20 years of experience in operations and supply chain, especially in production, logistics, and warehouse management. His special competencies include improving operational efficiency, implementing lean processes, and leading teams across complex supply chain functions. He has held key roles, including Production Manager at PT Mitra Galperti and Operations Manager at PT Ceva Logistics, and serves as a Practitioner Lecturer and Trainer in Supply Chain Management. He holds a Master's degree in Supply Chain Management from BINUS University and a Bachelor's degree in Industrial Engineering.

1 Introduction

Global supply chains have been exposed to more severe and prolonged disruptions, indicating structural weaknesses beyond firm-level operational vulnerabilities. Previous disruptions, including natural disasters, labour strikes, terrorist attacks, economic downturns, and technological changes (Ramezankhani et al., 2018; Parast and Shekarian, 2019), have long threatened the stability of supply chains, and it is considered a major risk that contributes to increasing overall uncertainty and risks on supply chain performance. These disturbances may block product or information flow and disrupt financial resources within supply chains, resulting in inefficiency and competitive disadvantage (Ramezankhani et al., 2018). Companies that are less likely to be agile and flexible tend to suffer the most from disruptions, whilst capabilities such as flexibility, collaborative approach, agility in manufacturing, and redundancy support resilient organisations by enabling better response strategies (Gunesee et al., 2018; Shekarian et al., 2020).

The COVID-19 outbreak posed a challenge to global supply chains, revealing how unprepared the industry was to handle disruptions on such a scale and prompting it to establish new practices to make them more robust (Van Hoek, 2020; Ivanov and Dolgui, 2020). Evidence of how fragile Indonesia's logistics setup is when disruptions occur was provided by data from the Central Bureau of Statistics, which showed steep declines in other sectors, including transportation and storage, in 2020. Overall, empirical research on pandemic disruptions has identified cancellations, operational disruptions, and shortages of goods and materials (Plaček et al., 2020; Sullivan and Wamba, 2022). Resilience will thus likely not only serve as a recovery condition, but also aid the continuity of business more generally, as resilient supply chains are better prepared to face and recover from disruptions (e.g., Ponomarov and Holcomb, 2009; Hendry et al., 2019).

But the disruption driven by the pandemic is only a part of the entire risk environment. Supply chains become vulnerable to alternative geopolitical risk enablers, such as trade wars, regulatory instability, sanctions regimes, and energy insecurity, which, by their nature, introduce long-term uncertainty about their continuation and exacerbate the disruption profiles of global supply networks (Parast and Shekarian, 2019; Hendry et al., 2019). This next wave of structural uncertainties can generate unceasing volatility in cross-border flows, sourcing dependability, and logistics-level continuity, thereby emphasising the newly identified strategic role of business dynamic capabilities as crucial pragmatic facilitators of adaptation and survival amid protracted disruption (Ivanov, 2022, 2024). In a volatile environment, organisations are required to be resilient not only in absorbing shocks but also in reconfiguring the resources and processes of a supply chain system (Teece, 2007, 2018). Geopolitical risk is relevant in producing shifts from compliance to deviance as a systematic, enterprise-level effect across diverse institutional contexts worldwide (Chang et al., 2025). Supplementary empirical studies, on the other hand, suggest that within the system, resilience is not an inherent characteristic but is dynamically mobilised as needed in response to disturbance-related events associated with integrated digital devices and technologies (Wu et al., 2025). These developments also offer both theoretical and empirical justification for at least two streams of research related to artificial intelligence (AI) and big data that treat AI or big data capabilities as dynamic capabilities necessary to mobilise organisational agility and resilience, and to support a continuous, redefined understanding of unpredictability.

The ambiguous context surrounding the use of AI and big data analytics (BDA) as strategic tools to improve visibility, decision quality, responsiveness, and risk mitigation motivates firms to adopt them (Schniederjans et al., 2020; Wang et al., 2016). AI-based systems applications, such as predictive analytics, machine learning, or automated decision support, comprise the prediction of upcoming system disruptions and optimal routing decisions, making it possible for organisations to reduce operational costs while improving supply chain agility (SCA) and resilience (Baryannis et al., 2019; Belhadi et al., 2022; Wong et al., 2022). Similarly, BDA capabilities improve prediction, visibility, and real-time tracking by converting diverse, massive datasets into actionable information that allows organisations to become agile (adaptive) or continuous through disruptions (Wamba et al., 2020; Nguyen et al., 2018). This is especially the case regarding real-time tracking, demand forecasting, inventory control, risk management services, dependability, and customer performance (Wang et al., 2016; Sullivan and Wamba, 2022) in time- and data-sensitive logistics, shipping, and freight-forwarding activities.

The empirical evidence is becoming clearer and larger, showing that shipping and logistics companies with AI-driven BDA achieve supply-chain performance orders of magnitude better. AI and data-driven applications in shipping companies can lead to superior operational performance through better routing, utilisation of capacity, and automation of documentation processes; at the same time, BDA allows for better inventory management (e.g., logistics services or products) and more accurate predictions of demand by linking real-time data from operation with market (Wang et al., 2016; Schniederjans et al., 2020). Additionally, with the use of real-time tracking and predictive risk analytics driven by AI and BDA, shipping companies can respond promptly in handling disruptions to service lines, making them a more reliable process, as well as resulting in a significant response rate (Sullivan and Wamba, 2022; Baryannis et al., 2019). Also, the need to improve performance is especially important in shipping and freight-forwarding operations, where time sensitivity, asset intensity, and exposure to global uncertainty all require digitally advanced capabilities to remain competitive.

Theoretically, this strategic positioning, in which AI and BDA are employed, aligns with Dynamic Capabilities Theory (Teece, 2007, 2018); having dynamic supply chain capability is fundamental for companies to sense industry shake-ups, seize opportunities arising from those changes, and reconfigure resources as conditions change. It is widely established in the literature that dynamic capabilities are operationalised, at the supply chain level, as SCA (the capacity to alter its operations and tactics with speed and precision so that it can respond rapidly to changing demand or supply conditions) and resilience (the ability of a system to mitigate, cope and recover from disruptions, and ensure continuous business continuity) (Dubey et al., 2018; Ponomarov and Holcomb, 2009; Ivanov, 2022). Essentially, without transforming AI and BDA into high-order capabilities (i.e., reconfiguration and survival mechanisms), granting firms agility (Dubey et al., 2024; Teece, 2007) will not achieve sustainable outcomes.

Recent research on the synergetic effects of AI and BDA is limited. First, the literature shows a limited understanding of the complementarity among agility, resilience, and performance (Zamani et al., 2023), as most studies have examined the impact of AI or BDA in isolation. Second, theoretical frameworks and empirical studies have often demarcated agility and resilience as respective mediating mechanisms through which digital capabilities improve performance and outcomes of the direct use of such digital resources (Bahrami et al., 2022). Third, it is acknowledged that structural uncertainty exists in the disruption literature; however, key contextual drivers, such as geopolitical risk, have yet to be adequately incorporated into empirical models of AI-enabled supply chains (Parast and Shekarian, 2019; Hendry et al., 2019).

In this study, we investigate the effects of AI and BDA capabilities on supply chain performance, both directly and indirectly (as mediators), and the relationships among SCA, resilience, and supply chain performance in logistics and freight forwarding companies in Indonesia to address these research gaps. Positioning AI and BDA within the framework of dynamic capabilities and embedding this analytically in an institutional setting characterised by systemic disruption pressure promotes practice-oriented theory building on how firms can utilise digital technologies to balance operational management with resilience and performance amid environmental change (Teece, 2007, 2018; Ivanov, 2022). On this premise, the following research questions provide direction for this study: What is the impact of AI and BDA capabilities on SCA and supply chain resilience (SCR) (Baryannis et al., 2019; Wamba and Akter, 2019)? How do SCA and resilience act as mediators between AI, BDA, and supply chain performance (Bahrami et al., 2022;

Sullivan and Wamba, 2022)? How do these digital-enabled dynamic capabilities improve the supply chain performance of logistics companies in systemically disrupted and uncertain environments (Ivanov, 2022; Teece, 2007)?

In doing so, this research contributes in three ways. First, it contributes to the literature on dynamic capabilities by providing empirical evidence on the mechanisms (agility and resilience) through which AI and BDA are operationalised into performance outcomes (Teece, 2007, 2018). Second, it advances the literature on supply chain risk by identifying environmental turbulence (and structural uncertainty, particularly regarding geopolitical pressures) as an important precursor of investment in digital capabilities (Parast and Shekarian, 2019; Hendry et al., 2019). Third, the results can support logistics managers and legislators in the Global South in designing supply chain systems that operate for longer during disruptions by leveraging concepts of agility and resilience (Tukamuhabwa et al., 2017; Ivanov, 2022).

The following section places our paper in context with prior literature, grounded in dynamic capabilities theory, and provides hypothesis development (Section 2). In Section 3, we describe how we collected our data and the measurement and analysis methods that underlie our approach. Section 4 integrates the theoretical framework, empirical findings, and implications with existing literature. Section 5 concludes the study by discussing limitations and directions for future research.

2 Literature review

Big data analytics and AI are technologies that can be used to build and enhance dynamic supply chain capabilities and performance. Resources encompass all assets a firm can draw on when formulating and implementing a strategy. On the other hand, capabilities are the organisational and managerial skills for managing a variety of resources and mobilising them effectively. Digital transformation dynamic capabilities can lead to competitive advantage (Dubey et al., 2024). Digital transformation can generate a competitive advantage through dynamic capabilities (Dubey et al., 2024). Dynamic capabilities are defined as the firm's ability to sense, seize, and reconfigure its knowledge assets, competencies, and complementary resources to sustain a competitive advantage by identifying and exploiting new opportunities. The capabilities include sensing, seizing, and transforming (Teece, 2018). These capabilities enable organisations to adapt by reconfiguring, integrating, and organising internal and external resources in response to a rapidly evolving business environment (Teece, 2007). Dynamic supply chain capabilities emerge when firms engage their employees to understand customer requirements and translate them into effective communication throughout the supply chain. The capabilities encompass market sensing, SCA, adaptability, and resilience (Dubey et al., 2018; Sabahi and Parast, 2019). In other words, capabilities can form a viable supply chain that encompasses agility, resilience, and sustainability (Ivanov, 2022). Gen AI significantly strengthens dynamic capabilities, especially in SMEs (Shore et al., 2024).

2.1 Artificial intelligence (AI)

Over the past 20 years, many organisations have significantly increased their digitalisation efforts. Recently, we have been hearing much more about Industry 4.0, which encompasses new technologies, such as AI, that enhance industrial operations

(Wollschlaeger and Sauter, 2017). Artificial intelligence (AI) has been a key enabler in this space, allowing all things and devices to talk (Lewis, 2019; Wong et al., 2022). Among all business functions, operations stand to benefit most from computer information systems, with decision-making processes accelerated and optimised (Schniederjans et al., 2020). While artificial intelligence is a relatively old technology, its function in supply chain management has recently received much media coverage. AI is characterised as having the intelligence to quickly alter decisions that the fast-paced present-day world necessitates, which, in terms of problem anticipation, can address potential issues before they arise and support customers with more transparency regarding good delivery; they will arrive intact without delay (Smyth et al., 2024; Sohrabpour et al., 2020).

AI applications in operations reduce operational and compliance costs and increase the efficiency of value chain networks (Dubey et al., 2020). Predictive analytics, particularly for demand forecasting, is one area where AI has had the greatest impact. In this fast-moving business environment, AI can predict demand by analysing trends, thus providing companies with a key to their competitive edge. Through personalised customer interactions and real-time shipment tracking, AI-powered bots further drive customer engagement (Huang and Rust, 2021). AI-powered automation has revolutionised logistics and warehousing. AI-powered robotics also increases warehouse productivity (Lu, 2019). For example, Alibaba and Amazon have incorporated robotics to allocate labour for streamlined operations. One AI application is optimising delivery routes, which enables time savings and cost reductions and is a critical advantage in supply chain operations, where every minute and mile counts (Shi et al., 2020).

AI is a cornerstone enabler in supply chain management, automating complex processes and supporting real-time decision-making. According to studies, AI increases operational efficiency, reduces costs, and enables faster responses to ever-changing markets (Grover et al., 2022; Baryanis et al., 2019). AI capabilities that use predictive analytics precisely predict demand based on customers purchasing behaviour. The capabilities process large volumes of data quickly; it also makes supply chains faster and more resilient, enabling businesses to respond effectively to changes in demand or external threats.

2.2 Big data analytics (BDA)

Big data analytics has drawn increasing attention in recent years, given its wide applications across industries, but the lack of a consistent definition of BDA has challenged researchers and practitioners alike. Big data analytics is a sophisticated set of technologies that learn from a vast, heterogeneous dataset at the speed of data capture and processing (Mikalef and Gupta, 2021). Such capabilities in data-driven decision-making provide organisations with a competitive advantage, particularly in skills, supply chain management, and performance (Dubey et al., 2020).

BDA, using specialised tools to analyse large volumes of data and extract actionable insights, shifts decision-making from intuition-based approaches to data-driven ones (Zhong et al., 2016). In the new era in which the Internet of Things (IoT) methods are widely regarded as part of corporate strategy, smartphones, RFID, cloud computing, and BDA have become common components of business interconnectivity (Yingfeng et al., 2017). Nevertheless, there are also hurdles, such as data uncertainty and confidentiality risks, in sensitive fields like healthcare (Engelseth and Wang, 2018; Hazen et al., 2014).

BDA improves green operational practices and decisions in operations and supply chain management (Palareti et al., 2016). Although it is often associated with AI, BDA is distinct. AI is associated with the human-like performance of machines (Wang and Pan, 2022); examples include predictive analytics and automated decision-making in supply chain management. AI drives agility and helps mitigate risk, while BDA evaluates data to improve analytical and predictive capabilities, enabling more accurate real-time forecasting and timely logistics monitoring (Bahrami et al., 2022; Zhuang et al., 2017). This difference also explains why BDA is used to generate insights, whereas AI needs to automate work processes to drive operational efficiency.

Big data analytics has emerged as essential to transforming supply chain management, enabling the analysis of large volumes of data to enhance decision-making, risk management, and operational efficiency. Research has evidenced that BDA organisations are more agile and flexible (Dubey et al., 2018). In addition to shortening lead times, it helps improve inventory levels and predict customer demand, both of which are crucial attributes of a responsive supply chain (Nguyen et al., 2018). BDA will help supply chain managers enhance supply chain resilience (SCR) by improving visibility and stability during disruptions. The combination of AI and BDA enables agility, resilience, and operational excellence in modern-day supply chain management.

2.3 Supply chain agility (SCA)

Supply chain agility (SCA) is a key driver of an organisation's capacity to innovate and economically provide products to its customers (Dubey et al., 2022). Supply chain agility is an important element for achieving success in highly competitive markets by matching supply with demand, reducing cycle times, and enhancing responsiveness (Abdallah and Ayoub, 2020). The SCA denotes the ability to react promptly to ever-changing business environments and to adapt over time (Jain et al., 2017; Tukamuhabwa et al., 2017). The ability to be agile, especially in today's highly volatile markets, allows organisations to adapt on the fly to production and logistics to reflect changing demand.

2.4 Supply chain resilience (SCR)

SCR refers to the ability of a supply chain to (cost-effectively and immediately) detect, prepare for, respond to and recover from any potential disruptive events (Ponomarov and Holcomb, 2009). These are strategies aimed at preventing or responding to mitigating supply chain disruptions (Zhang et al., 2022), making timely adjustments, and quickly re-establishing functional performance (Belhadi et al., 2022; Jain et al., 2017). SCR provides a structural approach to the timely delivery of goods and services, with an emphasis on efficient resumption following disturbances (Hendry et al., 2019; Bahrami et al., 2022). The pandemic led to various disruptions, so continuity was key, and resilience made it happen (Bahrami et al., 2022; Ponomarov and Holcomb, 2009). SCR exploration can be conducted from adaptation- and stability-based perspectives (Ivanov, 2024) and through the active use of resilience assets (AURA). Improvement of performance due to organisational agility and resilience. When a few supply chains are coupled with some dimensions of AI and BDA, they amplify these characteristics, resulting in less downtime, lower cost of execution, and a higher quality of service delivery. Hence, by deploying AI and BDA, uncertainty becomes manageable, making the supply chain more robust and efficient.

2.5 Supply chain performance (CP)

Measurable outcomes of business processes related to the supply chain, including on-time delivery, supply quality, responsiveness, operational efficiency, and process improvements, serve as objective benchmarks for assessing supply chain performance (Sullivan and Wamba, 2022). Previous studies have extensively documented the merits of BDA in reducing operational costs, increasing customer satisfaction, and increasing SCA (Oncioiu et al., 2019). One of the most common supply chain performance (CP) measurement frameworks is the supply chain operations reference or SCOR model developed by the Supply Chain Council in 1996. It provides an extensive structure with a metric hierarchy (Lima-Junior et al., 2016). The SCOR (Supply Chain Operations Reference) model maps all activities associated with meeting customer demand and is structured into four categories: process, practice, people, and performance. In its 11th iteration, it identifies six primary management processes: enabling, planning, returning, sourcing, delivering, and manufacturing.

The performance dimension groups metrics hierarchically as follows (APICS, 2017): responsiveness, agility, cost, and asset management efficiency. Metrics tied to another set of attributes, those secure, reliable, and quality-based requirements, can be used in the meantime, given the strategic goals expressed. Research on AI and BDA, although extensively studied separately, has few studies that jointly examine SCA, resilience, and company performance. Zamani et al. (2023) contend that AI and BDA are collaborative catalysts for supply chain performance by influencing firm effectiveness and supporting decision-making within the firm. AI helps humans adapt rapidly to disruptions, while BDA gives organisations early warning, enabling them to predict, prevent, and mitigate disruptions. AI and BDA positively impact financial and operational performance, as well as customer satisfaction (Eckstein et al., 2015).

2.6 Hypotheses development.

Baryannis et al. (2019) define AI as a method that independently evaluates actions to achieve risk-management goals, even when complete information about the supply chain is unavailable. AI enhances knowledge generation during disruptions by improving predictability and decision-making within the supply chain (Baryannis et al., 2019). Furthermore, AI innovation re-creates supply chain performance. Hence, AI is crucial to supply chain management (Sabri et al., 2018). Studies confirm that AI improves decision-making by enabling proactive and predictive capabilities. By employing adaptive and self-learning methods, AI enables machines to exhibit human-like reasoning (Belhadi et al., 2022).

New research suggests that the competitive advantages of analytics-heavy technologies lie in enabling rapid sensing, scenario assessment, and reconfiguration, functions that map closely onto the micro foundations of agility and resilience. The impact of analytical ability on resilience, and through it on performance outcomes, was moderated under the context of failed supply chain integration (Seif and Jafari, 2025). Likewise, insights from digital-technology portfolios suggest that when technologies are configured as complementary resource-oriented and action-oriented sets rather than a single investment-as-a-service (or Lego) plastic-type investment, the resilience gains may be maximised (Wu et al., 2025).

Geopolitical risk is emerging as one of the many disruptions in today's global supply chains, including trade tensions, regulatory balkanisation, sanctions, and energy insecurity. Such risks, in contrast to those that are episodic in nature, bring about prolonged and systemic uncertainty on the form of governance, including structure, coordination, and supply chain (Parast and Shekarian, 2019; Ivanov, 2024). Under these conditions, digital technologies like AI and BDA become more strategically important for firms, as they can help detect geopolitical signals, predict the propagation of disruptions and mitigations across supply chain resources, and aid in reallocation. Thus, from a dynamic capability perspective, geopolitical risk is neither a performance driver nor a factor highlighting the synthetic attributes rooted in SCA and resilience (Teece, 2007; Ivanov, 2022). Hence, the effects of AI and BDA on supply chain performance will presumably be most observable in contexts characterised by protracted geopolitical or systemic disruption. Geopolitical risk is a set of fundamental explanatory conditions that trigger and enable the dynamics associated with digital capabilities to attain agility and resilience.

In settings with high geopolitical risk, AI-powered predictive, sensing, and decision-support systems are useful for preparing for potential disruptions and planning adaptive responses. Therefore, the influence of AI technology on SCA and resilience is likely to be particularly pronounced during prolonged periods of uncertainty (Modgil et al., 2022).

H1: Artificial intelligence impacts supply chain agility.

H2: Artificial intelligence impacts supply chain resilience.

BDA capabilities that enable extreme SCA are closely associated with investments in supply chain visibility (Dubey et al., 2019). Compared with BDA used in organisations, it can effectively leverage existing knowledge to enhance SCR (Bahrami et al., 2022). According to Bahrami et al. (2022), BDA provides a competitive advantage and is a potent organisational lever for achieving an innovation-based market advantage. BDA drives operational excellence and yields a competitive edge. Its ability to provide the insights needed to react, recover, and adapt enables supply chains to become agile and resilient while increasing operational performance. Big data analytics enhances the visibility, coordination, and cross-border data integration capabilities of supply chain partners (Multi-Dimensional Insights) amid a disruptive, geopolitically charged regulatory landscape. It helps quick reconfiguration and recovery, leading to improved agility and robustness in the face of uncertainties.

H3: Big Data Analytics impacts supply chain agility.

H4: Big Data Analytics impacts supply chain resilience.

Gain the agility to reduce risk costs, especially in a competitive market with unpredictable profitability and supply chain. It helps a company streamline its operations and provide good customer service, driven by differentiation, thereby yielding profitable companies. Eckstein et al. (2015) argue that more agile companies are better suited to deal with disruptions at lower cost. On the other hand, SCR is a dynamic capability that strongly influences supply chain performance and the ability to deliver reliable service with minimal disruption in the face of challenges (Bahrami et al., 2022). Performance is largely a function of efficiency rather than adaptability or recoverability, if the geopolitical risk does not disrupt their cross-border flows and sourcing. Mediocre performance in a down system implies supply chain flexibility and robustness.

H5: Supply chain agility influences supply chain performance.

H6: Supply chain resilience influences supply chain performance.

AI can be applied to improve forecasting and planning, minimise waste, and reduce business risk. In addition, it enhances the supply chain's visibility and responsiveness, which are necessary for resilience in times of unpredictability (Zamani et al., 2023). AI reduces the likelihood of disruption and the need for confrontation with the future by strengthening the dynamic capabilities of sensing, seizing, and adapting. To build resilience during disruptions, manage the environment well, and demonstrate flexibility in reconfiguring tangible and intangible resources (Belhadi et al., 2024).

This is consistent with a mechanism-based perspective on the association, since many other studies also show that digital or analytics abilities function as performance-augmenting factors through resilience and adaptability channels, but not as direct drivers of efficiency-effect pathways (Seif and Jafari, 2025; Wu et al., 2025). The above support also justifies our claim that agility and resilience are mediating variables between AI or BDA capabilities and supply chain performance. Taken together, these hypotheses suggest that BDA and AI have an indirect effect on supply chain performance through the lens of agility and resilience theory, particularly in a chronically politically destabilised nation. This is because the logic is mediated by systemic risk, whereby digital capabilities mitigate the performance dividends of such a system.

H7: SCA mediates the effect of AI on supply chain performance.

H8: SCR mediates the effect of AI on supply chain performance.

BDA helps companies leverage new data types to improve business outcomes and accelerate problem-solving and operational adjustments (Oncioiu et al., 2019). BDA is an intelligent tool that supports cost reduction and value creation by enabling faster responses to changes and improved planning (Ren et al., 2016). Big data has influenced supply chain management by increasing network complexity and resilience (Bahrami et al., 2022). By increasing resilience and visibility, BDA reduces environmental uncertainty, thus improving the organisation's performance (Bahrami et al., 2022).

H9: The effect of BDA on supply chain performance is mediated by SCA.

H10: The effect of BDA on supply chain performance is mediated by SCR.

Although this investigation does not theorise geopolitical risk as a separate construct, it is anticipated to represent an important contextual boundary condition that will strengthen the relationships under study. Thus, the suggested hypotheses can be considered to operate in a context of heightened geopolitical and systemic turmoil, thereby enhancing their independent contribution and novelty.

3 Method

This study employed a quantitative approach with causal and explanatory aims, a survey design, and cross-sectional data collection. All the scales used a 1–5 Likert-type scale to measure their respective variables. This research uses non-probability sampling (purposive sampling), selecting individuals based on specific criteria aligned with the research objectives (Bougie and Sekaran, 2019). Respondents were employees (experts) of logistics service companies in Indonesia. The sample comprised 286 respondents. Data was analysed using SmartPLS. To assess data validity and reliability, the criteria include standardised factor loadings, composite reliability, average variance extracted, and Cronbach's alpha, as shown in Table 1.

Table 1 Validity and reliability test acceptance criteria

Items	*Validity*	*Reliability*	*Criteria*
SFL	≥0.7	–	Valid
AVE	≥0.7	–	Valid
CR	–	≥0.7	Reliable
CA	–	≥0.7	Reliable

This research model comprises five variables: AI and BDA as exogenous variables; SCA and SCR as mediating variables; and company performance as an endogenous variable. The five AI Indicators are operational risk (AI1), operational cost (AI2), IT issues (AI3), resource allocation and efficiency (AI4), and competitive edge (AI5). BDA has five indicators: forecasting future trends (BDA1), customer sentiment and preferences (BDA2), performance metrics (BDA3), data visualisation (BDA4), and interactive dashboards (BDA5). SCA includes five indicators: changes in the environment (SCA1), opportunities in the environment (SCA2), threats in the environment (SCA3), information from suppliers (SCA4), and information from customers (SCA5). SCR has five indicators: building robustness (SCR1), business continuity (SCR2), enhanced visibility (SCR3), dynamic management (SCR4), and crisis management (SCR5). Supply chain performance (CP) includes ten indicators: reliability (CP1), responsiveness (CP2), agility (CP3), operating efficiency (CP4), process improvement (CP5), SCM total cost (CP6), COGS cost (CP7), asset management cash-to-cash cycle (CP8), asset management return-to-fixed assets (CP9), and asset management return-on-working-capital (CP10).

Hypothesis testing is preceded by several checks to assess the adequacy and quality of respondents as well as the appropriateness of the analytical method. The sample size was assessed for adequacy using the common rule of thumb in PLS-SEM: it should be at least 10 times the number of variables. The minimum sample size is at least 10 times the maximum number of structural paths of the model directed at any construct (Hair et al., 2019). The one with the most incoming paths is supply chain performance, which has two antecedents: SCA and SCR. Second, PLS-SEM was chosen for its applicability to predictive studies, complex models with mediation effects, and the relatively small-to-medium sample size of this study. PLS-SEM is particularly applicable when the purpose of the investigation is to extend or test a theory by explaining variance in endogenous constructs, rather than conducting strict theory testing (Hair et al., 2019; Sarstedt et al., 2022). Third, the goodness of fit of the measurement model was examined using reliability and validity analyses. The indicators of validity and reliability are shown in Table 1, including discriminant validity, which was tested using the Fornell–Larcker criterion and the HTMT ratio.

Before the hypotheses were tested, several checks were performed to assess the adequacy and quality of the respondent data and the appropriateness of the analytical approach. First, the sample size was assessed for adequacy using the 10-times rule of thumb, which is typically used in PLS-SEM. At a minimum, the sample size should be 10 times the maximum number of structural paths directed at any construct in the model (Hair et al., 2019). The one with the most incoming paths is supply chain performance, which has two antecedents (SCA and SCR) in this research. Second, PLS-SEM was chosen for its applicability to predictive studies, complex models with mediation effects, and the relatively small-to-medium sample size of this study. PLS-SEM is particularly applicable when the purpose of the investigation is to extend or test a theory by explaining variance in endogenous constructs, rather than conducting strict theory testing (Hair et al., 2019; Sarstedt et al., 2022). Third, the goodness of fit of the measurement model was examined using reliability and validity analyses. The indicators of the validity and reliability are shown in Table 1, including discriminant validity, which was tested using the Fornell–Larcker criterion and the heterotrait–monotrait (HTMT) ratio.

4 Results and discussion

4.1 Respondents profile

As many as 77% of respondents were older than 25 years. Their positions are as follows: 47% are staff, followed by managers (25%), supervisors (21%), and senior managers or directors (7%). Regarding primary roles, most participants are involved in business development (37%), operations (34%), IT (14%), and sourcing or procurement (14%). Their experience is more than 5 years (up to 40%) or less than 5 years (up to 60%). The respondents' profiles indicate a good understanding of the company's supply chain, as their roles were closely associated with supply chain responsibilities. Their company locations are in the Jakarta area (approximately 56%; Jakarta, Bogor, Depok, Tangerang, and Bekasi), with the remainder outside it.

4.2 Validity and reliability

Based on the validity and reliability tests presented in Tables 2–4, and Figure 1, the data showed strong convergent and discriminant validity and reliability, evidenced by metrics such as standardised loading factors (SFL), average variance extracted (AVE), Composite Reliability (CR), and Cronbach's Alpha (CA). In the second round of testing, indicators AI2 and CP3 were removed because of invalid results.

4.3 Hypotheses tests

According to the R-square values presented in Table 5, the endogenous variable 'supply chain performance' has an R-square of 0.409, indicating that SCR and SCA explain 40.9% of its variation. Similarly, 'supply chain agility' has an R-squared of 0.441, indicating that 44.1% of its variance is explained by artificial intelligence and big data capabilities. An R-square value of 0.400 for SCR suggests that 40% of its variation is explained by AI and BDA capabilities.

Table 2 Convergent validity

		Standardised loading factor	
Variable	*Indicator*	*Phase 1*	*Phase 2*
Artificial intelligence (AI)	AI1	0.863	0.875
	AI2	0.446	–*
	AI3	0.838	0.850
	AI4	0.718	0.703
	AI5	0.854	0.863
Big data analytics (BDA)	BDA1	0.760	0.760
	BDA2	0.782	0.782
	BDA3	0.781	0.781
	BDA4	0.773	0.773
	BDA5	0.822	0.822
Company performance (CP)	CP1	0.764	0.770
	CP2	0.739	0.746
	CP3	0.574	-*
	CP4	0.736	0.738
	CP5	0.772	0.777
	CP6	0.789	0.793
	CP7	0.760	0.753
	CP8	0.743	0.746
	CP9	0.796	0.795
	CP10	0.845	0.847
Supply chain resilience (SCR)	SCR1	0.864	0.865
	SCR2	0.749	0.747
	SCR3	0.804	0.806
	SCR4	0.782	0.780
	SCR5	0.854	0.855
Supply chain agility (SCA)	SCA1	0.760	0.759
	SCA2	0.802	0.804
	SCA3	0.718	0.716
	SCA4	0.793	0.795
	SCA5	0.759	0.758

*Insignificant.

Table 3 Results of validity and reliability tests

Items	*CA*	*CR*	*AVE*
AI	0.841	0.895	0.682
BDA	0.844	0.889	0.615
CP	0.917	0.931	0.659
SCA	0.825	0.877	0.588
SCR	0.870	0.906	0.556

CA: Cronbach’s alpha; CR: Composite Reliability; AVE: Average Variance Extracted.

Table 4 Discriminant validity (Fornell-Larcker criterion)

Items	*AI*	*BDA*	*CP*	*SCA*	*SCR*
AI	0.826				
BDA	0.702	0.784			
CP	0.580	0.598	0.775		
SCA	0.617	0.609	0.515	0.767	
SCR	0.591	0.576	0.584	0.495	0.812

Figure 1 SmartPLS results: Algorithm (see online version for colours)

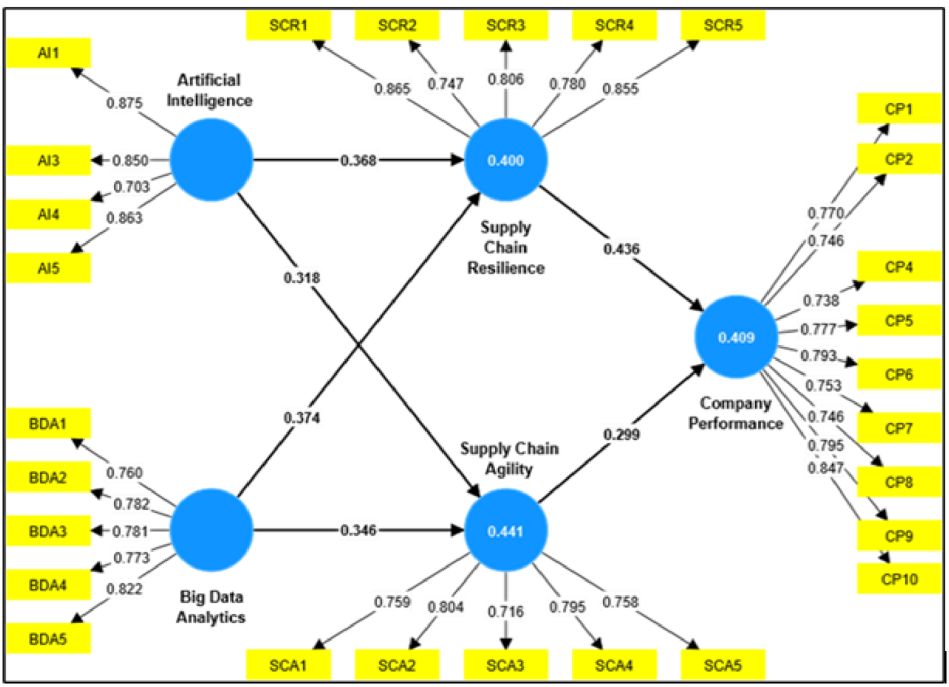
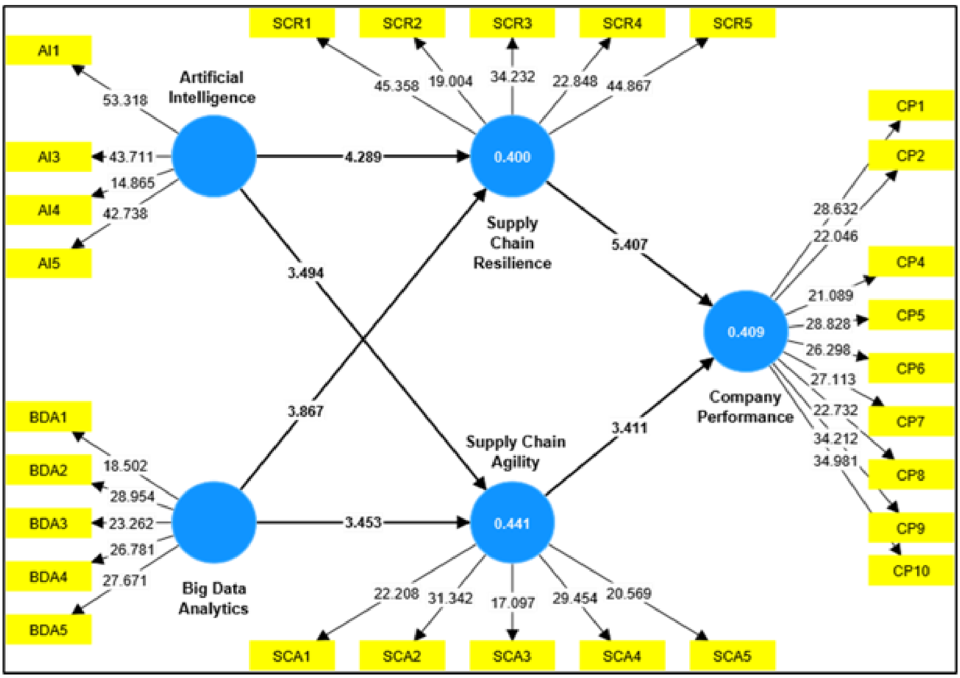


Table 5 R-square value

Items	*R-square*	*R-square adjusted*
Company performance (CP)	0.841	0.682
Supply chain agility (SCA)	0.844	0.615
Supply chain resilience (SCR)	0.917	0.659

Based on the hypothesis-testing results in Figures 1 and 2, Tables 4 and 5, artificial intelligence (AI) and big data (BDA) capabilities generally have positive and significant effects on SCA and SCR. Additionally, SCA and SCR mediate the influence of AI and BDA on company performance (CP). This means that a best-fit approximation indicates AI accounts for 37% of the variance in SCA (H1) and 36% in SCR (H2), with the remainder explained by other variables across the two populations. The model explains around 65% of the variance in SCA (H3) and 68% in SCR (H4), with BDA effects accounting for about 35% and 32% of the variance attributable to external factors, respectively. The influence of SCA on CP (H5) is 30%, and the SCR perspective on CP (H6) is 44%, with others influencing the rest. In addition, significant mediation by SCA (H7 and H8) and SCR (H9 and H10) is evident in the pathways from AI to CP via BDA.

Figure 2 SmartPLS results: Bootstrapping (see online version for colours)



The empirical results validate the positive impact of AI and BDA on SCA, resilience, and performance. The theory is developed by studying the mechanisms through which these technologies generate value. In the Dynamic Capabilities Theory (Teece, 2007, 2018), AI and BDA are not levers for increasing a firm's efficiency; rather, they enable a firm to sense, seize, and reconfigure capabilities in supply chains. AI intermediates sensing through enhanced prediction and accelerated disruption identification. BDA intermediates seizing and reconfiguring by facilitating data-driven coordination and operational agility. This partly explains why companies with stronger AI and BDA capabilities are better able to respond to uncertainty and perform better amid disruption.

The current reading leads us towards an area that has been thoroughly examined, comprising research that most directly addresses the instrumental use case for digitalisation (Baryannis et al., 2019; Schniederjans et al., 2020). The strategic value in considering how AI and BDA can be integrated into organisational routines that support agility and resilience, rather than viewing these as separate technology investments.

This aligns with the more recent view that intermediary capabilities are beneficial only when bundled into higher-order dynamic capabilities (Dubey et al., 2024; Ivanov, 2022).

Arguably, the most important theoretical conclusion of this research is that SCA and resilience are not merely outcomes but mediating constructs in the relationships between AI and BDA investment. The mediation findings illustrate that AI and BDA enhance supply chain performance by significantly increasing firms' capacity for rapid adaptation (agility) and their ability to absorb or recover from shocks (resilience). This result helps fill a significant gap in prior studies, which often report direct effects of digitalisation on performance without clarifying the nature of the changes being undertaken (Bahrami et al., 2022; Sullivan and Wamba, 2022).

The biggest theoretical contribution this research makes is that SCA and resilience are mediating constructs, not simply outcomes of investment in AI and BDA. This research contributes to the supply chain literature by shedding light on the capability transformation process, digital technologies, dynamic capabilities, and performance, and by providing empirical evidence for the mediating roles of agility and resilience. This perspective aligns with the new resilience frameworks that favour preparedness and adaptive reconfiguration over transient efficiency (Ivanov, 2022; Ivanov, 2024). This also clarifies why so many companies have been unable to turn their digital investments into productivity gains: it requires an organisational capability to convert insight into action; just rolling out tech is insufficient. The findings are particularly pertinent for periods of systemic shock (e.g., geopolitical risk, regulatory uncertainty, long-term threats to supply). These disturbances require continuous adjustment and not episodic recovery, unlike transitory shocks.

The positive impact of AI and BDA on both agility and resilience in this study indicates that digital capabilities are particularly beneficial in environments of embedded uncertainty. Supply chain disruptions are less severe when businesses respond in time to signals from an AI-led early warning system (e.g., complex behavioural and environmental indicators in a volatile geopolitical region) and gain a better understanding of the business ecosystem (i.e., BDA and sense-making enhance transparency and coordination). This contribution to existing research on disruption, which has predominantly focused on pandemic-induced business risks or operational uncertainty (Hoek, 2020; Ivanov and Dolgui, 2020), indicates that digitally enabled dynamic capabilities are also important under structural and long-term uncertainty.

In this way, the study informs current debates about SCR by showing that sustainable performance is contingent on firms integrating digital technologies into dynamic capability systems (vs. using static risk-mitigation solutions). With respect to novelty, the study does not advance new relationships per se but establishes existing mechanisms of digital capability in relation to geopolitical risk. The influence of AI and BDA on agility, resilience, and performance is established in the existing literature (Zhou et al., 2019), but this study demonstrates that these relationships assume even greater strategic importance when actors face prolonged geopolitical and systemic dislocation. Whereas previous work has mostly theorised about efficiency-based explanations for performance resilience amidst chaotic uncertainty at the global level, this paper retheorises existing hypotheses as contextual capacity mechanisms for organisations. The results are more than just the individual hypothesis test; they are at the model level, where AI and BDA capabilities improve supply chain performance, mediated by SCA and resilience. The structural model clearly states that digital transformation is not a performance driver but rather operates through capability development to support firms in being adaptive, responsive, and resilient under uncertain conditions.

More specifically, the model demonstrates how AI and BDA serve as building blocks that affect agility and resilience, ultimately influencing supply chain performance. This pattern shows that, rather than merely adopting advanced technology, becoming more data-driven also entails the organisational capability to translate digital insights into more nuanced and adaptive recovery actions. Agility is, in effect, the firm's ability to quickly reorganise itself in response to demand fluctuations and signals of disruption; resilience is the firm's ability to absorb shocks and recover continuity. The model therefore emphasises that a logical sequence provides digital capabilities that reinforce adaptive supply chain capabilities, and that these capabilities, in turn, sustain performance. The results also indicate that agility and resilience are highly mediating constructs, suggesting that the direct effects of technology on performance may be insufficient to explain digital value creation in the supply chain. Whereas previous studies tend to emphasise direct efficiency gains from implementing AI and analytics, the model suggests that these gains are contingent on dynamic supply chain capabilities.

This result reflects a dynamic capabilities view of AI and BDA, in which their effects on performance are mediated by sensing, seizing, and reconfiguring activities embedded in agility and resilience (Helfat and Peteraf, 2007), rather than by direct input variables that optimise outcomes. The framework also contains recommendations on how companies manage systemic, continuous disruption, such as geopolitical instability. Supply chain performance in such cases is thus less about how well things are set up (static optimisation) than about adaptability and recovery. The results support the contention that AI and BDA affect performance indirectly by strengthening these adaptive mechanisms, providing the firm with ways to deal with persistent uncertainty, regulatory instability, and international disruption. In this manner, it advances current research on digital supply chains by focusing not only on technology deployment but also on capability transformation paths.

Taken together, the contributions generated by the model advance practical and theoretical understanding by integrating AI and BDA capabilities with supply chain flexibility, resilience, and performance into a theoretical framework. It identifies the what, why, or how of digital technologies that enable supply chain performance, claiming that agility and resilience are not normative ends; rather, they represent a means through which the long-term benefits of value-based digital transformation are derived.

4.4 Research implications

Artificial Intelligence (AI) has optimised supply chain management in this environment, allowing for a flexible response to changing market conditions and operational disruptions. AI will enhance the supply chain's agility more quickly and provide a more precise response to changes in demand and supply. For example, AI-powered demand forecasting predicts consumer demand and minimises lead times, while logistics automation reduces errors and enhances responsiveness. Such adaptability gives AI-driven companies an advantage over those that rely on traditional methods, as they can respond to market shifts more quickly, resulting in less waste, improved inventory management, and stronger just-in-time production, thereby reducing costs and keeping customers satisfied. However, challenges exist with AI adoption in supply chains because it may require a significant infrastructure overhaul, and businesses need teams with the skills to design and manage AI systems. In addition, although data scientists can extract machine-readable patterns from unstructured data, AI only works if companies can access high-quality data; otherwise, it is ineffective.

AI helps strengthen SCR, enabling it to withstand disruptions and recover faster when they occur. AI predicts likely disruptions, e.g., natural calamities, by analysing national and environmental data. This provides companies with early warning, allowing them to take proactive steps (e.g., diversifying suppliers). Although exploiting AI in resilience strategies could help, it needs to be managed carefully, as overreliance on it without human supervision becomes a liability, especially in complex situations that are better evaluated by human flames. Political risk has been shown to negatively impact global SCA (for example, Chang et al., 2025). The evidence highlighted above shows that policymakers and regulators should focus on delinking actions that entail cross-border spillovers while simultaneously supporting firms' continuation through sufficient risk disclosure, harmonisation of data-sharing arrangements, and promotion of investment in resilience.

Managers need to consider AI and Big Data capabilities as a pair of complementary investments, one that needs to be fitted into cohesive digital capability portfolios and decision routines; recent evidence has demonstrated that there are returns to resilience when firms orchestrate their digital technologies for both 'resource-oriented' and 'action-oriented' implementation (Wu et al., 2025) or translate analytics capability into mechanisms that enhance resilience capabilities adding performance impact (Seif and Jafari, 2025).

Big data analytics (BDA) enables firms to conduct real-time data analysis, predict rapidly changing demand, optimise transportation routes, and manage inventory. However, this is offset by challenges such as data silos, poor data quality, and narrow integration, which limit BDA implementation, as well as by a lack of analytical tools or expertise. It offers proactive risk management that supports resilience. The ability to analyse data in real time provides early insights into disruptions, increased transparency, and better decision-making. However, BDA only works when the data are accurate, and data sharing among partners is stable.

In volatile markets, the topline capability of a supply chain remains highly sensitive to signals that determine its agility and resilience. Agility enhances the ability to respond quickly to change, which helps their clients and staff respond positively and be more productive, whereas Resilience helps work continue despite sudden, unexpected, large numbers of people moving away from performing. The introduction of AI and BDA in traditional supply chain systems leads to an agile, resilient supply chain with higher operational efficiency, improved customer satisfaction, and greater profitability, while providing a sustainable competitive advantage.

The results of the study reaffirm established notions that automation and intelligent systems allow firms to respond quickly to changes in the markets (Baryannis et al., 2019); and the necessity of proactive capabilities to mitigate disruptions (Ponomarov and Holcomb, 2009); assert that data-driven insights help to respond rapidly to emerging market conditions (Grover et al., 2022); and show that through data analytics, visibility and insights are enhanced, enabling organisations to anticipate better and respond to challenges (Nguyen et al., 2018). Agility is also identified as a key success factor in competing markets (Dubey et al., 2019). Resilience is increasingly portrayed as critical to business continuity (Hendry et al., 2019). Supply chain agility accentuates the positive relationship between AI and operational performance, SCR enhances the value of AI (Modgil et al., 2022), SCA equips organisations to exploit data analytics to achieve performance gains, and SCR to exploit the full potential of analytics (Bahrami et al., 2022). These results are also in line with more recent empirical evidence suggesting that analytics-driven capabilities directly enhance firm outcomes, not so much as purely direct performance drivers, but as the building blocks of resilience (Seif and Jafari, 2025).

They complement recent research on digital resilience, suggesting that it is not simply the level of investment in technology per se, but rather the framing of it as combinations or 'bundles' of complementary technologies and how these are unpacked through coordinated supply chain actions (Wu et al., 2025). Importantly, particularly in the context of viewing our findings alongside geopolitical instability, we argue that increasingly capabilities for operating in radically uncertain environments allow some organisations to perform better across their supply chain, with global evidence now linking political risk to reductions in SCR (Chang et al., 2025). Investments into agility and resilience become particularly meaningful.

Managerially, the results of this study have significant implications for managers in logistics, transportation, and supply-chain-dominant industries. First, the benefits indicate that AI and BDA do not directly contribute to supply chain performance; rather, they must be translated into SCA and resilience. This points to the need for managers to go beyond ad hoc technology applications and instead embed AI and BDA in decision routines, coordination mechanisms, and disruption-response processes necessary for proactive adaptation or recovery. Heterogeneous processes and organisation that can be quickly reconfigured will make investment in digital technologies more productive when the going gets tough. Second, the robust mediating roles of SCA and resilience imply that managers should regard these two capabilities as strategic goals (not merely as side effects of digitalisation). AI-driven forecasting, scenario analysis, and early warning systems, for example, should be tailored to equip organisations with the agility to respond in real time to demand shocks and set them up for a resilient recovery from disruptive events. As in this case, BDA needs to be leveraged to improve visibility, partner coordination, and cross-functional integration in logistics networks, which are characterised by lengthy periods of high-level uncertainty. Thirdly, in a systemic and geopolitical (des)stabilisation environment, AI and BDA should be perceived by managers as risk-prone and resilience-building structures rather than cost-saving mechanisms. Results show that firms that can translate digital capabilities into agility and resilience are better able to sustain their performance over the long term amid chronic instability. This underscores the importance of leadership commitment, capability building, and upskilling to bridge the gap between digital insights and operational action in a timely manner.

Beyond firm-level decision-makers, the findings have implications for regulators or policymakers interested in promoting supply chain stability that supports national economic resilience. According to the research, digital capabilities fuel performance through agility and resilience, pointing to policies that drive technology adoption and build capability. Governments and regulators may help to most effectively facilitate this transition by incentivising investment in digital infrastructure, ensuring a common set of data-sharing standards, and building interoperable platforms from node to node along the supply chain logistics and transportation system between producers (upstream), distributors (downstream), including those who distribute directly, warehousing and holding providers, as well as retailers. That means AI- and BDA-enabled supply chains would also be more resilient to persistent disruptions arising from geopolitical risk, regulatory uncertainty, and cross-border instability. From a policy perspective, this demonstrates the necessity to advance digital transformation as part of wider national resilience and supply security strategies. For example, public-private partnerships to enhance access to and development of analytics capabilities, increase adoption of digital logistics platforms, and foster greater collaboration in monitoring supply chain risk can support systemic preparedness and resilience.

The social implications of this research extend beyond organisations to broader social outcomes. More agile and resilient supply chains benefit society by enabling the delivery of critical products and services (especially during crises or disruptions). AI and BDA enable rapid response and the repurposing of supply chains to adapt to shortages, quickly stabilise distribution mechanisms after short-term demand fluctuations, and reduce social costs associated with supply chain disruptions. Strong supply chains are also vital for equity and inclusion, as these events should be free from discrimination. This ensures improved access to food, medical supplies, and other essentials through resilient logistics systems and response efforts. Thus, even from this perspective, investments in digital supply chain assets have consequences for both firms' competitive positions and public resilience and social sustainability. An effective digital supply chain can help achieve more sustainable economic development by reducing the impact and duration of disruptions and increasing public confidence in institutions that operate critical infrastructure. Accordingly, the results point to the need to embed digital supply chain strategies within broader socioeconomic and policy goals regarding resilience, equity, and future well-being.

5 Conclusion

The integration of artificial intelligence and big data capabilities enhances SCA and resilience, thereby improving performance. As a result, businesses that adopt artificial intelligence (AI) and BDA are better able to detect disruptions, mitigate risks, and improve their decision-making; hence, they adapt more effectively to market changes, enjoy greater operational agility, and react more quickly to sudden events. The research further shows that AI and BDA capabilities should be transformed into SCA and resilience as part of dynamic supply chain capabilities to improve supply chain performance. With these supply chain technologies, logistics companies are poised for growth through cost savings, enhanced customer satisfaction, and operational excellence in volatile environments. Integrating AI and BDA as strategic enablers to build SCA and resilience for logistics companies, especially in developing countries like Indonesia, with a holistic solution to build robust supply chains. The findings of this study help companies enhance their performance through technological innovation.

Notwithstanding its contributions, the present study has some limitations that should be acknowledged and serve as a basis for future research. First, this research relied on a cross-sectional study design; no significant inferences can be drawn about the dynamic relationships among AI, BDA, SCA, resilience, and performance. A direction for future research is to adopt a longitudinal view and investigate how digital and dynamic supply chain capabilities evolve over time, particularly during long-lasting disturbances such as geopolitical issues or regulatory constraints, despite the theoretical justification and statistical significance of the results here.

Second, the empirical data are from logistics service experts in an emerging economy (Indonesia). Although this setting is of direct significance for its exposure to institutional instability and the threat of disruption, it also introduces idiosyncrasies that may limit the generalisability of some findings to other settings. Future research can also incorporate cross-country or multi-regional comparisons (e.g., developed vs. emerging economies) to further examine the different institutional contexts and geopolitical exposures through which enhanced AI- and BDA-enabled supply chain capabilities are effective.

Thirdly, AI and BDA are the core digital capabilities that this research seeks to enhance. Still, we exclude many other digital technologies, such as blockchain, digital twinning, IoT, and generative AI. The following directions for future research extend the model by considering digital capability portfolios and complementarities among multiple technologies, as well as the joint effects of these factors on agility, resilience, and performance.

Fourth, this study is theoretically situated within the context of systemic and geopolitical disturbances; geopolitical risk is not measured as an independent construct. Explicit geopolitical risk indicators or indices can be added, and future research can also explore their (moderating or mediating) effects on digital capabilities and supply chain outcomes. This extension would also address the implications and/or drivers of global political dynamics for SCR and performance.

Lastly, this study uses self-reported survey data that may be susceptible to perceptual biases, even though established measurement and validation protocols were employed. Since they are designed to combine survey-based approaches with case studies (or mixed-methods designs incorporating objective performance data), they may increase both the validity and the richness of insights into how digital technologies are practiced, which future research should consider. Future studies could help develop a theory of digital transformation and dynamic capabilities in supply chains by addressing these gaps and, more broadly, examining how firms can adapt amid increasing uncertainty and continuous disruption.

Acknowledgement

This study was funded by Bina Nusantara University, Grant Number: 174B/VRRTT/VIII/2025. Acknowledge: We are thankful for the funding that supported this research.

Conflicts of interest

The authors declare that there are no conflicts regarding the publication of this paper. The authors do not have competing professional, financial, or personal interests that could have appeared to impact the research, analysis, interpretation of data, or the writing of this manuscript.

Authors' contributions

Conceptualisation: D.S., A.L.N., and D.A; Methodology: D.S. and A.L.N; Software: A.L.N and D.A; Data Validation: D.S. and A.L.N; Formal Analysis: D.S., A.L.N., and D.A.; Writing Original Draft Preparation: D.S., A.L.N., and D.A; Writing Review and Editing: D.S. and D.A.; Funding Acquisition: D.S.

Data availability statement

The data that support these findings cannot be publicly shared due to privacy and legal restrictions. You may, upon reasonable request and provided that the relevant approvals and compliance with applicable data protection laws have been granted or come without any input from our side (and/or at your own expense), be given access to such limited information. The required data can be obtained by contacting the corresponding author.

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