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Digital transformation in supply chains: improving resilience and sustainability through AI, Blockchain, and IoT

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Background: Global supply chains are increasingly challenged by disruptions, environmental pressures, and evolving market demands, necessitating a strong digital transformation. This study explores how the integration of Artificial Intelligence (AI), Blockchain, and the Internet of Things (IoT) is revolutionizing supply chain management (SCM) by improving operational efficiency, transparency, resilience, and sustainability.

Methods: Adhering to the PRISMA framework, a systematic review of literature published between 2010 and 2024 was undertaken. Comprehensive searches were conducted in Scopus database. The collected literature was rigorously screened and analyzed using Atlas-ti software to identify recurring themes and assess the synergistic impact of AI, Blockchain, and IoT on supply chain operations.

Results: The review reveals that digital transformation significantly improves SCM through improved demand forecasting, optimized inventory management, and real-time decision-making capabilities. AI provides predictive insights that mitigate risks and streamline processes, Blockchain offers secure, transparent, and immutable records that improve trust and traceability, and IoT enables real-time monitoring and connectivity across the supply chain network. Despite these benefits, challenges remain, including cybersecurity vulnerabilities, interoperability with legacy systems, and the need for workforce upskilling.

Conclusion: The integration of AI, Blockchain, and IoT into SCM presents a compelling pathway toward creating more resilient and sustainable supply chains. The paper offers a comprehensive analysis of the benefits and challenges associated with these digital technologies and provides strategic recommendations for practitioners and policymakers to encourage a balanced, technology-driven, and sustainable supply chain ecosystem.

JEL codes: O33, M11, M15

KEYWORDS

artificial intelligence, blockchain, digital transformation, supply chain resilience, sustainability, Internet of Things

1 Introduction

The global supply chain landscape has been confronted with an increasing number of disruptions, which have emphasized the necessity of improved sustainability and resilience. The COVID-19 pandemic and other recent events have emphasized the vulnerabilities in supply chains, resulting in significant operational disruptions and increased costs. Organizations have been compelled to reconsider their supply chain strategies in response to these disruptions,

with an emphasis on adaptability and flexibility to reduce the risks associated with unforeseen events (Deng, 2023). A transition to more sustainable practices that can withstand such shocks is required due to the complexities of global supply chains, which are further complicated by geopolitical tensions and environmental challenges (Zhu and Wu, 2022).

Sustainability in supply chains is no longer a peripheral concern; it is a fundamental component of contemporary business strategy. The integration of sustainability into supply chain management entails the consideration of economic, environmental, and social dimensions, which collectively contribute to long-term viability and competitiveness (Li, 2023). Companies are increasingly acknowledging that sustainable supply chains can mitigate adverse environmental effects, including greenhouse gas emissions and resource depletion, while simultaneously improving their reputational capital and regulatory compliance (Chen, 2023). The demand for sustainable practices in supply chains has been further fueled by the increased consumer expectations for corporate responsibility, which has been a result of the increasing global awareness of environmental issues (Hindarto, 2023).

Supply chains are being transformed to become more sustainable and resilient as a result of technological advancements, particularly in the areas of Artificial Intelligence (AI), Blockchain, and the Internet of Things (IoT). For example, the Internet of Things (IoT) facilitates the real-time monitoring of goods and resources by improving visibility and traceability throughout supply chains (Zafar, 2024). This heightened transparency is crucial for the attainment of sustainability objectives, as it enables more informed decision-making and promotes collaboration among supply chain partners (Sallam et al., 2023). Supply chain operations are optimized, disruptions are predicted, and proactive responses to potential challenges are enabled by AI technologies (Aliahmadi et al., 2022). Blockchain technology improves trust and accountability in supply chains by generating immutable transaction records, which can assist in the mitigation of issues related to fraud and corruption that undermine sustainability efforts (Mumin et al., 2024).

The concept of supply chain agility is also essential in the context of sustainability. Agility enables organizations to promptly adapt to fluctuations in demand or supply conditions, thereby ensuring operational continuity and reducing waste (Pratondo et al., 2021). This adaptability is crucial for the sustainability of economic, social, and environmental systems, as it allows organizations to align their operations with sustainable practices while simultaneously satisfying customer expectations (Zhu and Wu, 2022). Empirical studies have shown that resilient supply chains are more likely to achieve sustainability objectives, and the relationship between resilience and sustainability is becoming more widely acknowledged as a critical element of effective supply chain management (Zhu and Wu, 2022).

Supply chain management (SCM) has become critically dependent on digital transformation, particularly considering the challenges presented by global disruptions like the COVID-19 pandemic. The integration of advanced technologies that improve decision-making, improve operational efficiency, and encourage resilience within supply chains is the defining characteristic of this transformation. The integration of digital technologies, such as Artificial Intelligence (AI), Blockchain, and the Internet of Things (IoT), is transforming conventional supply chain methodologies, allowing organizations to react more adeptly to market variations and operational challenges.

Digital transformation's significance in supply chain management is further emphasized by its capacity to improve supply chain resilience. The capacity of supply chains to anticipate, prepare for, respond to, and recover from disruptions is referred to as resilience. Research has shown that organizations that adopt digital transformation are more capable of identifying and analyzing weak links in their supply chains, thereby enabling the continuous reconfiguration of network mapping to balance supply and demand during disruption events (Modgil et al., 2021). Additionally, the integration of AI technologies enables supply chain managers to make informed decisions that improve responsiveness and agility by integrating real-time data analysis (Mohsen, 2023). This capability is especially important in the context of unpredictable disruptions, as the performance of the supply chain can be significantly impacted by timely information (Golan et al., 2020).

Resilience and sustainable practices within supply chains are significantly influenced by advanced technologies. For example, AI improves operational efficiency by optimizing a variety of supply chain components, such as inventory management, demand forecasting, and logistics (Chukwu et al., 2024). AI's predictive capabilities enable organizations to anticipate disruptions and modify their strategies accordingly, thereby reducing risks and improving the overall performance of their supply chains (Bidin, 2024). Furthermore, the utilization of artificial intelligence (AI) in supply chain risk assessment improves safety and resilience by analyzing extensive data sets to anticipate potential disruptions prior to their occurrence (Narayanan et al., 2024). Drawing from the background of this study, the research objectives are: To examine how the integration of AI, Blockchain, and IoT improves supply chain resilience and sustainability; To analyze the challenges and opportunities associated with adopting these digital technologies in contemporary supply chain management; To develop strategic recommendations for practitioners and policymakers to effectively implement digital transformation initiatives in supply chains.

The significance of examining the integration of AI, Blockchain, and IoT in supply chains is that it addresses critical challenges in the current volatile global market. The real-time tracking, predictive analytics, and automated decision-making capabilities of these advanced technologies collectively offer transformative potential to improve supply chain resilience, thereby reducing disruption risks. The integration encourages sustainability by optimizing resource allocation and minimizing waste, resulting in environmentally conscious operations. This study offers critical insights into the synergies and challenges of merging these digital tools, thereby informing both academic research and industry practices. The study assists supply chain managers, policymakers, and stakeholders in the development of innovative strategies that improve transparency, efficiency, and adaptability by investigating the practical implications of such integration. This study advocates for the transformation of contemporary supply chains into more sustainable, secure, and agile systems, thereby promoting economic

growth in a global landscape that is becoming increasingly interconnected and complex.

The digital transformation of supply chains is of the utmost importance in the current resource-constrained, volatile environment, in which firms are confronted with unprecedented disruptions, including pandemics, geopolitical tensions, and climate-induced shocks. This study addresses a clear gap in both scholarly literature and managerial practice regarding integrated digital strategies for enhancing supply-chain resilience and sustainability by investigating the combined potential of artificial intelligence (AI), blockchain, and the Internet of Things (IoT). AI-driven analytics can facilitate proactive risk forecasting, while IoT sensor networks enable real-time visibility and adaptive response mechanisms. Blockchain further guarantees transactional transparency and trust among diverse stakeholders. Investigating the interaction and reinforcement of these technologies provides unique insights into system-level design principles that improve supply chain strength, reduce waste, and promote circular economy practices. Policymakers will be informed about regulatory frameworks that encourage sustainable, digitally enabled supply networks, and practitioners will be guided in their technology investment decisions by empirically grounded recommendations. The results will ultimately contribute to the theoretical understanding of socio-technical integration and facilitate the transition to more environmentally responsible, resilient global supply chains.

The study is organized into discrete sections, starting with an overview of the research problem, and concluding with an extensive literature review on supply chain AI, blockchain, and IoT. The research approach is described in the methodology section, which is followed by the results and discussion sections that highlight the main conclusions and their implications. Lastly, future research directions and recommendations for industry practitioners are offered. The focus of the scope is the integration of digital technologies to improve sustainability and resilience.

This study is divided into six sections, with the introduction providing a comprehensive overview of the challenges faced by global supply chains and the necessity of digital transformation. The literature review synthesizes existing research on AI, Blockchain, and IoT, while the methodology section delineates the systematic literature review approach. The conclusion comprehensively identifies avenues for future research and offers strategic recommendations, while the results and discussion sections analyze the impact of these technologies on resilience and sustainability.

2 Literature review

2.1 Overview of digital transformation in supply chains and its evolution

Over the past decade, the digital transformation of supply chains has gone through a significant transformation, in part due to the advancements in technologies such as the Internet of Things (IoT), Blockchain, and Artificial Intelligence (AI). Traditional supply chain models are being transformed into more efficient, transparent, and agile systems that improve sustainability and resilience because of this transformation. The integration of these technologies enables the sharing of real-time data, improved decision-making, and increased visibility across supply chain networks, all of which are critical for navigating the intricacies of contemporary supply chains.

The role of AI in supply chain management is crucial, as it enables organizations to respond quickly to market changes and disruptions by facilitating improved planning and forecasting through data analytics. AI-driven analytics can improve inventory management, anticipate demand fluctuations, and simplify operations, thereby improving the overall resilience of the supply chain (Pflaum et al., 2021; Reynolds, 2024). However, the integration of IoT devices improves visibility and transparency, enabling stakeholders to track the status of goods in real time. This is essential for ensuring operational efficiency and reducing the risks associated with supply chain disruptions (Pflaum et al., 2021; Stroumpoulis and Kopanaki, 2022).

Supply chain management is further transformed by Blockchain technology, which offers a decentralized, unchangeable ledger that improves data integrity and traceability. This technology promotes collaboration among supply chain partners by addressing critical challenges, including counterfeit goods and cumbersome documentation processes (Oriekhoe et al., 2024; Revathi et al., 2024), For example, research has demonstrated that blockchain technology can improve the efficiency of the supply chain by as much as 74% and significantly decrease the time necessary for digital documentation (Rijanto, 2021). However, blockchain's capacity to deliver real-time visibility throughout the supply chain improves operational efficiency and facilitates sustainable practices by allowing improved tracking of products and materials (Hasan and Habib, 2022; Revathi et al., 2024).

The adoption of these digital technologies is not without challenges, despite the numerous benefits. The integration of new technologies into existing systems, the necessity of upskilling personnel, and the initial investment costs associated with the implementation of advanced technologies are frequently challenges that organizations encounter (Kozhanov and Woebbeking, 2021). Furthermore, logistics professionals are generally skeptical of the efficacy and security of blockchain and other digital tools, which may inhibit their widespread adoption (Priyadarshi and Asif, 2023). Nevertheless, the perceived usefulness of these technologies can influence the willingness of supply chain professionals to adopt them, emphasizing the necessity of demonstrating tangible benefits (Junejo et al., 2023).

Strategy recommendations for practitioners and policymakers to effectively implement digital transformation initiatives in supply chains include the following: cultivating a culture of innovation and collaboration among stakeholders, investing in training and development to improve digital literacy, and establishing clear frameworks for data governance and security (Zhao et al., 2022). Policymakers should also take into account the development of regulatory environments that are conducive to the adoption of digital technologies, while simultaneously addressing concerns regarding data protection and privacy (Ioannou and Demirel, 2022).

2.2 The integration of AI, Blockchain, and IoT in supply chain operations

The integration of the Internet of Things (IoT), Blockchain, and Artificial Intelligence (AI) in supply chain operations is a transformative shift that improves sustainability and resilience. Each of these technologies makes a distinctive contribution to the improvement of operational efficiency, transparency, and responsiveness in supply chains. AI is essential for the optimization of supply chain processes by analyzing vast amounts of data to forecast demand, manage inventory, and identify potential disruptions. For example, AI algorithms can anticipate supply chain disruptions by examining historical data and current trends, thereby facilitating proactive risk management strategies (Prasad et al., 2024). Additionally, artificial intelligence (AI) improves decision-making capabilities by automating processes and offering insights that can result in more efficient operations (Wang et al., 2024). The integration of AI and IoT facilitates real-time oversight of supply chain operations, crucial for ensuring product quality and safety (Rui and Sundram, 2024).

Blockchain technology gives supply chain operations an additional degree of security and transparency. A decentralized and tamper-proof ledger is provided, which improves traceability and accountability throughout the supply chain (Charles et al., 2023). For instance, blockchain technology can guarantee that food products are sourced sustainably and safely by monitoring their journey from farm to table in the agri-food sector (Rui and Sundram, 2024). Fuyao et al. (2023) asserts that this capability not only encourages consumer confidence but also assists organizations in abiding by regulatory mandates. The secure sharing of data collected from IoT devices is made possible by the combination of blockchain and IoT, which is essential for the preservation of supply chain information (Charles et al., 2023).

Enabling real-time data collection and analysis, the Internet of Things (IoT) facilitates the seamless integration of a variety of supply chain components by connecting devices and systems (Karthik and Jagadeesan, 2023). This connectivity facilitates improved inventory management and production tracking, which are essential for a prompt response to market demands (Ning and Yao, 2023). IoT devices are capable of monitoring environmental conditions, including temperature and humidity, which are essential for the preservation of product quality, particularly in the food and pharmaceutical sectors (Alhamda and Rahman, 2022).

However, the adoption of these technologies is not without challenges. Organizations encounter challenges including elevated implementation expenses, insufficient technical proficiency, and apprehensions related to data privacy and security (Ali and Aboelmaged, 2021). Furthermore, the interoperability of various technologies can present significant challenges, as supply chains frequently involve numerous stakeholders with varying degrees of technological sophistication (Hussain et al., 2021). The integration of AI, Blockchain, and IoT presents significant opportunities, despite these challenges. These encompass augmented operational efficiency, diminished waste, and elevated customer satisfaction via superior service delivery (Singh, 2024).

Strategic recommendations for practitioners and policymakers to effectively implement these digital transformation initiatives include the following: investing in training and development to develop technical expertise, encouraging collaboration among supply chain partners to ensure interoperability, and developing strong data governance frameworks to address privacy and security concerns (Holloway, 2024b). Additionally, policymakers should contemplate the establishment of incentives to encourage organizations to implement these technologies, thereby encouraging a more sustainable and resilient supply chain ecosystem (Ning and Yao, 2023).

2.2.1 Ethical concerns in blockchain adoption: data privacy and energy footprint considerations

The implementation of Blockchain technology in supply chains involves numerous ethical concerns, including energy footprint and data privacy. Navigating these implications for environmental sustainability, societal benefits, and transparency is essential, in accordance with the overarching theme of digital transformation in supply chains. Data privacy is a significant ethical challenge that is linked to Blockchain technology. Although blockchain is acknowledged for its improved security and decentralized nature, it also has inherent issues, particularly in terms of the privacy implications associated with the storage of personal data. The application of the General Data Protection Regulation (GDPR) in relation to blockchain, as Jusić (2022) has discussed, emphasizes the challenges of identifying data controllers and ensuring that rights to data correction and deletion are upheld in an immutable ledger environment. Additionally, Mustafa et al. (2024) suggest that blockchain challenges well-established concepts of anonymity and decentralization in e-government settings, emphasizing a conflict between privacy and transparency.

The primary challenge is the necessity of maintaining a balance between the rights of individuals whose data may be captured on blockchain networks and the necessity for transparency in supply chains. As emphasized in works that evaluate blockchain solutions for privacy enhancement in distributed systems (Anand, 2025), blockchain can improve traceability and accountability, facilitating a transparent flow of information. However, it is imperative that individuals' data privacy be protected. Dugyala et al. (2024) emphasize that stakeholder engagement is essential in resolving these ethical dilemmas. The energy footprint of blockchain adoption is another urgent ethical issue, especially regarding proof-of-work systems, which are the foundation of many cryptocurrencies. The energy-intensive nature of these systems presents significant environmental challenges. Ogunbiyi-Badaru et al. (2024) expresses these concerns, highlighting how the extensive adoption of blockchain technology disrupts conventional systems and prompts enquiries regarding environmental sustainability and its impact on global energy consumption challenges.

Alternatively, the ethical implications of blockchain technology may also extend to societal equity, as the environmental costs are frequently borne by lower-income communities, potentially exacerbating existing inequalities (Ogunbiyi-Badaru et al., 2024). The adoption of sustainable practices within blockchain initiatives can improve operational efficiency and financial outcomes

(Adhikari et al., 2025). However, this must be balanced against the energy requirements of the technology. Yu's (2024) research establishes a connection between blockchain and buisness ethics and social sustainability, urging companies to implement blockchain in order to reduce their energy consumption and promote a sustainable future. This emphasis on sustainability emphasizes the necessity of a responsible approach to blockchain development, as numerous scholars have emphasized the significance of frameworks that encourage ethical and sustainable practices (Li et al., 2024).

2.3 IoT and RFID concepts for the digitalization and contribution toward supply chains

The digital transformation of supply chains is dependent on the integration of the Internet of Things (IoT) and Radio Frequency Identification (RFID). This integration is essential for the improvement of sustainability and resilience. These technologies offer strong instruments for optimizing supply chain operations by improving data analysis, monitoring, and tracking, all of which are essential for meeting the evolving needs of contemporary markets. Supply chains have been transformed by RFID technology, which, as an enabler of Industry 4.0, offers real-time visibility of goods as they progress through the supply chain. Detailed product information and automated data collection are provided by RFID tags, which significantly improve operational efficiency (Khan et al., 2020; Pallathadka et al., 2022). This technology enables supply chain participants to manage product flows and track inventory levels more effectively, thereby reducing both stockouts and overstock situations (Pallathadka et al., 2022; Zelbst et al., 2019). The application of RFID technology not only improves the traceability of products, but also improves operational efficiency, which is essential for ensuring compliance with environmental and safety standards (Purandare and Aliakbarian, 2023; Reddy et al., 2023).

Furthermore, the integration of RFID and IoT technology enables the development of a sophisticated framework for data collection and analytics, which is crucial for the development of well-informed decision-making. The potential for automation and connectivity between various supply chain nodes is expanded by the integration of IoT with RFID, which improves coordination and responsiveness (Adeusi et al., 2024; Tan et al., 2021). Data can be collected from RFID tags that are embedded in products by IoT devices, which enables improved visibility across the supply chain network. Supply chain resilience is improved by this interconnectedness, which allows stakeholders to respond promptly to disruptions or fluctuations in demand (Reddy et al., 2023; Varriale et al., 2021). Waste and inefficiency in supply chains are significantly reduced by RFID and IoT in terms of sustainability. By optimizing logistics processes and facilitating precise inventory management, RFID technology directly reduces the environmental impact of supply chains (Buková et al., 2021; Purandare and Aliakbarian, 2023). The capabilities of IoT can help promote sustainable practices, including the reduction of waste and the monitoring of energy efficiency, by improving process automation and dynamic resource allocation (Adeusi et al., 2024). RFID's use in industries like clothing and agriculture serves as another example of how these technologies support ethical production and sourcing methods (Menanno et al., 2023). However, the implementation of these innovative technologies is not without challenges, such as the necessity of strong cybersecurity measures to safeguard sensitive data and the high initial investment costs (Abdulghani et al., 2022). Companies also need to manage the challenges of incorporating RFID and IoT systems into current procedures without interfering with ongoing business operations (Khan et al., 2020).

2.4 Challenges such as interoperability, cybersecurity and workforce upskilling on digital transformation on supply chains

Digital transformation within supply chains, particularly through the integration of Artificial Intelligence (AI), Blockchain, and the Internet of Things (IoT), offers substantial benefits for improving sustainability and resilience. The need for workforce upskilling, cybersecurity, and interoperability are among the significant challenges that accompany these advancements. The interoperability of diverse technological platforms is one of the most significant challenges to digital transformation. Ouchtout et al. (2025) emphasize that the amalgamation of AI, IoT, and Blockchain technologies frequently encounters challenges pertaining to semantic standards and system interoperability. These interoperability challenges have the potential to impede the seamless integration and sharing of data across various stages of the supply chain (Ouchtout et al., 2025). Similarly, Delviana and Endo (2024) emphasizes that the absence of standardization and the diversity of blockchain architectures impede the collaboration of supply chain partners, thereby diminishing the benefits of transparency and efficiency. Additionally, Wong et al. emphasize that the diverse array of systems that are currently in use frequently results in integration complexities that restrict the full potential of digital technologies (Holloway, 2024a).

The digital era presents supply chains with an additional critical barrier: cybersecurity. Supply chain systems become more susceptible to cyber threats as they become more interconnected and dependent on digital technologies. Holloway observes that organizations must confront substantial data security concerns and the potential for breaches, which can result in substantial financial and reputational harm (Holloway, 2024b). Additionally, Singh identifies that digital transformation enhances visibility and agility, but it also exacerbates the risks associated with data privacy and security breaches. Consequently, it is necessary to establish robust cybersecurity frameworks to protect sensitive information (Singh, 2023). The incorporation of IoT and Blockchain, as per a report by Rejeb et al. (2019) expands the attack surface for cyber intrusions, necessitating the development of innovative security solutions that can accommodate these new vulnerabilities.

Workforce upskilling is critically important, yet it is frequently disregarded in discussions of digital transformation. Due to the accelerated integration of AI, Blockchain, and IoT into supply chain operations, employees are required to acquire new skills

that are frequently absent from the current workforce. For the effective implementation of these technologies, Chen (2024) contends that it is imperative to address workforce skill gaps. Similarly, Hasan et al. (2023) suggest that the success of digital transformation is contingent upon ongoing education and training. Companies must allocate resources to training initiatives that not only improve technical competencies but also cultivate a culture of adaptability to accommodate ongoing technological advancements, as a result of the intricacies of digital systems (Rui and Sundram, 2024).

2.5 Case studies illustrating successful integration of AI, Blockchain, and IoT within supply chains

The integration of Artificial Intelligence (AI), Blockchain, and the Internet of Things (IoT) is transforming supply chain management by augmenting resilience and sustainability via improved data transparency, traceability, and decision-making proficiency. Each of these technologies makes a significant contribution to the resolution of common supply chain challenges, particularly in the context of global disruptions and the emphasis on sustainable practices. Predictive analytics and automated decision-making are two ways in which AI improves supply chain management. Modern supply chains, as Lai emphasizes, are increasingly dependent on AI to overcome challenges, which allows companies to anticipate demand and optimize logistics operations (Lai, 2024). Artificial intelligence-driven algorithms analyze extensive datasets from Internet of Things (IoT) devices to optimize inventory levels, thereby reducing waste and supporting sustainability initiative. For example, the bullwhip effect can be significantly reduced by incorporating AI into inventory management, which ensures that inventory more closely follows real-time demand (Muhamed et al., 2022). AI systems also enable businesses to make better forecasts by analyzing past data, which improves supply chain efficiency.

The distributed ledger system that blockchain technology provides is essential for the improvement of transparency in supply chains, as it guarantees secure and immutable transaction records. Cocco et al. (2021) emphasized a case study in which blockchain was implemented in a traditional bakery, resulting in improved traceability of ingredients. This improvement in food safety and the establishment of consumer trust were the results (Cocco et al., 2021). The blockchain's capacity to securely document each transaction allows all parties involved in the supply chain to access product history in real time, thereby facilitating compliance with regulatory standards and high-quality assurance. Additionally, Saberi et al. (2018) observe that blockchain has the potential to significantly reduce counterfeiting and fraud in supply chains by enhancing the trust of stakeholders through the provision of transparent and verifiable records.

IoT device integration is necessary for supply chains to collect and monitor data in real time. IoT sensors gather information like location, temperature, and humidity, which can be validated and stored on the blockchain for increased security and integrity. Real-time monitoring of pharmaceuticals in the healthcare sector by means of IoT devices enables stakeholders to monitor conditions throughout the supply chain, thereby guaranteeing patient safety and drug efficacy (Alhamda and Rahman, 2022). This close integration facilitates the timely resolution of any discrepancies in the supply chain, thereby increasing resilience. Wong et al. (2024) contend that the integration of blockchain and IoT improves traceability and mitigates fraud, thereby safeguarding the supply chain from a variety of vulnerabilities.

The agricultural sector serves as an outstanding illustration of successful integration, as AI, blockchain, and IoT intersect to facilitate "smart agriculture". Ahmed et al. (2022) have observed that this integration enables farmers to implement climate-smart techniques that enhance yield while reducing environmental impact, thereby enabling the precise monitoring and management of agricultural practices. This comprehensive approach provides producers with essential information, including soil conditions and weather patterns, enabling them to make data-driven decisions that are consistent with sustainability objectives.

The importance of 5G networks is essential in this triadic integration, as they enable faster communication between connected devices. The efficiency and resilience of supply chains are improved by the rapid processing and dissemination of data collected through IoT devices across blockchain systems, which is ensured by this technological backbone (Brown et al., 2024). The convergence of AI, Blockchain, and IoT not only improves operational efficiency but also promotes a sustainable approach to supply chain management. Companies can align with the increasing global emphasis on environmental stewardship by constructing systems that are responsive to market demands and committed to sustainable practices, which can be achieved by utilizing these advanced technologies (Chen, 2024).

2.6 Examination of resilience and sustainability concepts in supply chain management

The integration of technologies such as the Internet of Things (IoT), Blockchain, and Artificial Intelligence (AI) has made the examination of resilience and sustainability concepts in supply chain management increasingly relevant in the context of digital transformation. These technologies not only improve operational efficiency but also significantly contribute to the sustainability and resilience of supply chains, which are essential in the highly volatile market environment of today.

Digital transformation is acknowledged as a critical factor in the reshaping of supply chain strategies to achieve sustainability. Pyun and Rha (2021) emphasize the necessity of the digital transformation of supply chains for the sustainable viability of firms in the era of Industry 4.0. They propose that technologies such as AI, Blockchain, and IoT are essential for the implementation of digital supply chains. Zhao et al. (2023) assert that digitalization promotes efficient data sharing among supply chain partners, thereby enabling collaborative decision-making that improves flexibility and responsiveness to risks. Leveraging real-time data and analytics, this interconnectedness is essential for the

development of resilience, as it enables organizations to promptly adjust to disruptions (He et al., 2024).

The significance of AI in improving the resilience of supply chains is not overstated. Samuels (2025) explain that artificial intelligence (AI) can reduce the bullwhip effect, which frequently results in inefficiencies in supply chains, by facilitating more precise demand forecasting and inventory management. It is imperative to possess this capability to ensure operational continuity during disruptions. Furthermore, the incorporation of AI promotes superior governance and risk management via advanced monitoring mechanisms (He et al., 2024). A more agile supply chain that is more resilient to external shocks is the result of these deteriorations .

Blockchain technology is also instrumental in the promotion of sustainability within supply chains. It improves transparency and traceability, which are indispensable for sustainable practices. Nandi et al. (2020) states the implementation of Blockchain technology can improve the efficiency of financial, information, and material flows, thereby improving the overall performance of the supply chain. Consumers and regulatory bodies alike are increasingly requiring transparency to guarantee adherence to environmental standards and cultivate trust among stakeholders (Stroumpoulis and Kopanaki, 2022).

Furthermore, the IoT enables real-time surveillance and data acquisition, which are essential for improving supply chain efficiency. The capacity to collect and evaluate data from diverse sources enables companies to make informed decisions that improve efficiency and sustainability (Pflaum et al., 2021). IoT devices can assess environmental conditions and resource consumption, allowing companies to minimize waste and improve their sustainability metrics (Haddud and Khare, 2020). This corresponds with the conclusions of Zhang et al. (2020), who claim that big data analytics can markedly improve decision-making processes in supply chain management, resulting in improved sustainability outcomes.

Nevertheless, the implementation of these digital technologies is not without its challenges. Integration, data security, and the necessity of skilled personnel to oversee these sophisticated systems are all challenges that organizations must confront (Ning and Yao, 2023). Tsipoulanidis and Nanos emphasize that the COVID-19 pandemic has revealed the vulnerabilities of global supply chains, highlighting the necessity for digital transformation to improve resilience and sustainability (Tsipoulanidis and Nanos, 2022). As a result, in order to fully realize the advantages of digital transformation in supply chains, practitioners and policymakers should prioritize the development of strong frameworks for technology integration, the investment in training, and the cultivation of a culture of innovation.

2.7 The Technology-Organization-Environment (TOE) framework in digital supply chain transformation

The Technology-Organization-Environment (TOE) framework offers a comprehensive perspective for the analysis of digital transformation in supply chains. The adoption of technology is influenced by external environmental pressures, organizational readiness, and technological capabilities, as emphasized by TOE. In this context, the technical potential, integration feasibility within supply chain systems, and competitive pressures that drive their adoption are evaluated for AI, Blockchain, and IoT. Using the TOE framework, the study investigates the ways in which these digital technologies improve the resilience and sustainability of the supply chain, thereby addressing internal challenges and capitalizing on external market opportunities.

2.8 Best practices to overcome the challenges such as cybersecurity risks and interoperability issues

Significant challenges arise in the context of digital transformation within supply chains, particularly through the integration of advanced technologies such as the Internet of Things (IoT), Blockchain, and Artificial Intelligence (AI). These challenges are tied to interoperability issues and cybersecurity risks. Best practices that leverage both strategic innovations and technological advancements are necessary to overcome these challenges and ensure the seamless functioning of interconnected systems. AI and Machine Learning (ML) can significantly improve the protection of IoT environments against the rapidly changing cyber threat landscape by integrating them into cybersecurity protocols. Artificial intelligence-driven solutions offer proactive measures that can identify and respond to threats in real time, thereby reducing the potential for damage (Salem et al., 2024; Savu and Mitan, 2024). For instance, sophisticated AI algorithms can analyze network behavior to identify anomalies that suggest security breaches, thereby allowing organizations to act promptly and safeguard their sensitive data (AboulEla et al., 2024).

Additionally, it is imperative to implement a defense-in-depth strategy, which involves the implementation of numerous security controls to safeguard IoT devices and networks. This encompasses the implementation of encryption, secure access protocols, and consistent software updates to mitigate the risks associated with antiquated systems (Alajlan et al., 2023). The current literature emphasizes the importance of comprehensive frameworks that prioritize the continuous monitoring of IoT devices and risk management, which are frequently the weakest links in a cybersecurity strategy (Raghavendra and Yesaswini, 2024). These practices can be effectively integrated into governance models that can enhance the resilience of supply chains by ensuring data integrity and encouraging trust among stakeholders. Within digital supply chains, the interoperability of a variety of systems and technologies continues to be a significant challenge, particularly when integrating blockchain with IoT applications. Effective interoperability guarantees that various technologies can communicate and function in a cohesive manner, thereby enhancing operational efficiency (Kayikçi and Subramanian, 2022). Clear interoperability frameworks that address data formats, protocols, and interfaces used within supply chain systems must be defined through collaborative efforts among industry participants and standards development organizations.

However, the decentralized nature of blockchains presents distinctive challenges to achieving cross-platform operability. These challenges can be resolved by implementing API standardization and interoperability layers. Mezquita et al. (2023) states that shared standards-based collaborative ecosystems can facilitate the integration of diverse technologies and facilitate more seamless transactions, thereby improving the overall resilience of the supply chain. The literature demonstrates that a proactive approach that prioritizes the establishment of best practices and industry-wide cooperation can result in more strong interoperability solutions (Mezquita et al., 2023).

3 Methodology

3.1 PRISMA methodology

Supply chain digital transformation literature can be rigorously synthesized using PRISMA, or Preferred Reporting Items for Systematic Reviews and Meta-Analyzes. This study employs PRISMA to systematically gather, assess, and summarize evidence regarding the integration of AI, Blockchain, and IoT to improve sustainability and resilience. The review guarantees transparency, reproducibility, and reliability in the identification of challenges and opportunities within contemporary supply chain management by adhering to PRISMA guidelines. This systematic approach directly supports the objectives to evaluate the technological impact and provide strategic recommendations for effective implementation, thereby advancing the understanding of digital transformation from Industry 4.0 to emerging paradigms.

3.2 Inclusion and exclusion criteria

The selection criteria for literature in this systematic review are meticulously crafted to provide a comprehensive synthesis of the most recent research on the integration of AI, Blockchain, and IoT into supply chain management, with a particular emphasis on optimizing sustainability and resilience. The application of these technologies within contemporary supply chain contexts must be explicitly addressed in studies, in accordance with the progressive industrial paradigms from Industry 4.0 to emerging frameworks. Priority is given to research that investigates environmental and social sustainability outcomes, as well as demand forecasting, inventory control, transportation logistics, and supplier collaboration. The inclusion of only studies published in English from 2010 onwards that employ strong methodological approaches, whether empirical research, theoretical analysis, case studies, or systematic reviews to ensures relevance and reliability. This excludes articles that do not emphasize the digital transformation of supply chains or merely restate well-established findings. To ensure academic rigor, non-peer-reviewed sources, opinion pieces, and studies that lack sufficient methodological details are omitted. This meticulous curation ensures that the review offers reliable insights, which are essential for our investigation of the ways in which advanced digital technologies improve the efficiency, transparency, and adaptability of supply chain operations.

The Scopus database was used to identify 5,051 records, which commenced the process. Before screening, 298 duplicate records were eliminated, leaving 4,753 unique records for evaluation. A total of 2,007 records were requested for retrieval during the initial screening phase as the study limited to business management and accounting, with 2,746 records being excluded due to criteria such as relevance to the research question and methodological rigor. Therefore, 1,322 full-text article documents were subjected to the eligibility review; however, 685 of these records were not retrievable. At this point, 1,068 records were eliminated due to factors like missing information or the inability to access the complete text. As a result, 254 studies were determined to be appropriate for inclusion in the final analysis.

The collection of 254 studies that resulted from the systematic exclusion of publications that did not meet the predefined criteria whether due to irrelevance, methodological weakness, or unavailability offers a focused and credible foundation for the investigation of how AI, Blockchain, and IoT can collectively drive digital transformation in supply chains toward greater resilience and sustainability.

3.3 Search strategy

The search strategy for this study was meticulously designed to align with the research objectives. We conducted a thorough search of reputable database, such as Scopus to guarantee that scholarly articles, conference papers, and industry reports were completely covered. Keywords such as “Digital Transformation” “Sustainability”, “Resilience” “artificial intelligence”, “Blockchain”, “IoT”, and “supply chain management” were meticulously refined, and Boolean operators such as AND, OR, and NOT were implemented to improve the precision of the search. This rigorous approach enables the researcher to conduct a comprehensive analysis of the ways in which the integration of these digital technologies improves the resilience and sustainability of the supply chain, as well as the challenges and opportunities that are associated with contemporary supply chain management.

To address our research objectives, a comprehensive search string was developed to capture literature on digital transformation in supply chains. The search string that was used: ((“Digital Transformation” OR “Smart Supply Chain” OR “Supply Chain Resilience” OR “Supply Chain Sustainability”) AND (“Artificial Intelligence” OR “AI”) AND (“Blockchain”) AND (“Internet of Things” OR “IoT”) AND (“Supply Chain Management” OR “SCM”)). This string was applied across Scopus database, for publications from 2010 to 2024. This systematic approach ensures retrieval of relevant studies addressing technological integration, challenges, and strategic recommendations for digital supply chain initiatives.

3.4 Data extraction and synthesis method

The systematic literature review for this study was conducted in accordance with the PRISMA framework for data acquisition and synthesis, which was meticulously designed. This methodology

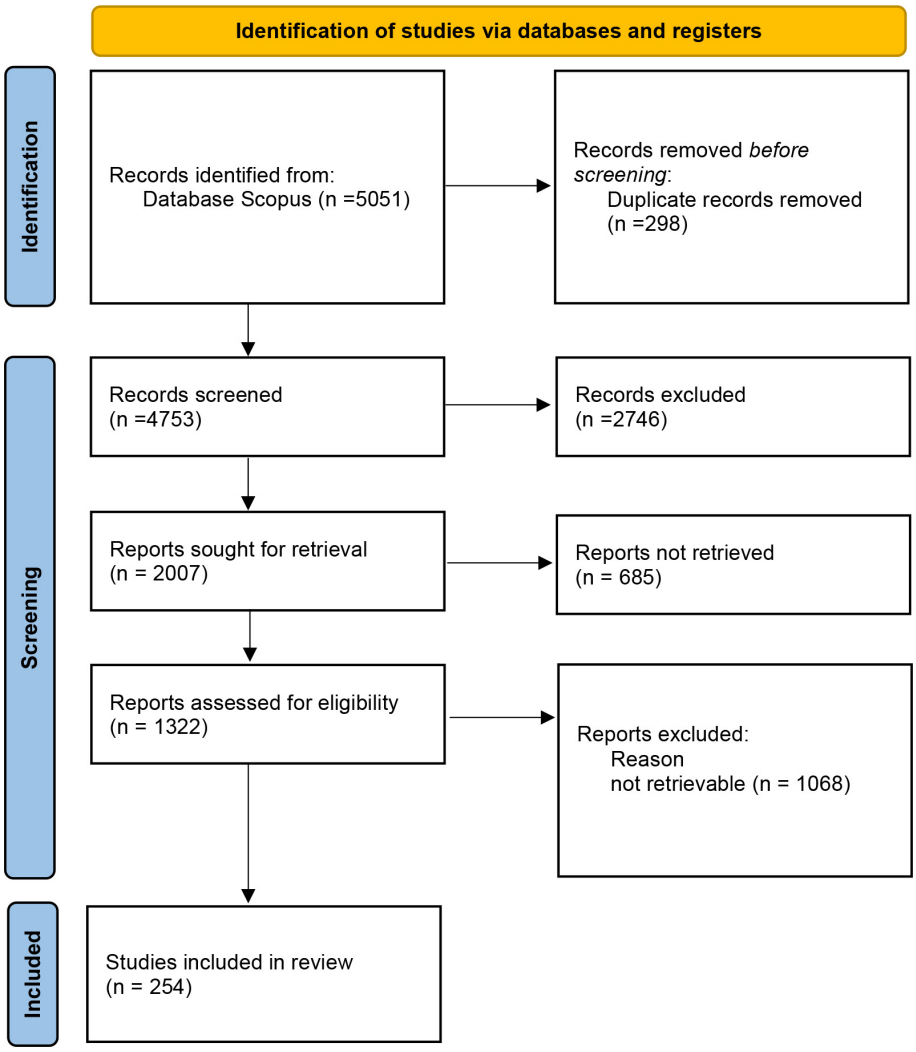

FIGURE 1
PRISMA framework. Source: Rethlefsen et al. (2021).

guaranteed the transparent and thorough identification, selection, and integration of literature that was relevant to our research objectives. These objectives include the analysis of the challenges and opportunities associated with the integration of AI, Blockchain, and IoT in contemporary supply chain management, the development of strategic recommendations for practitioners and policymakers, and the analysis of how the integration of these digital technologies improves supply chain resilience and sustainability. The above diagram labeled Figure 1, provides the initial search produced a significant number of publications from multiple databases, with the timeframe being set between 2010 and 2024 to encompass both seminal and contemporary contributions. The academic strength and pertinence of the review were ensured by the rigorous application of inclusion and exclusion criteria to exclusively include high-quality, pertinent studies.

The process of data extraction entailed the systematic collection of critical information from each selected article, such as the study objectives, methodologies, significant findings, and implications for digital transformation in supply chains. To guarantee comprehensiveness and consistency, a standardized data extraction form was implemented. Thematic analysis was employed to synthesize the extracted data, which resulted in the identification and categorization of recurring patterns, technological advancements, integration benefits, challenges, and strategic recommendations. This thematic synthesis facilitated the development of coherent narratives that comprehensively address the study's objectives, thereby providing valuable insights into the cumulative contributions of AI, Blockchain, and IoT to the improvement of supply chain resilience and sustainability.

3.5 Quality assessment of the selected studies

To ensure that the results of this systematic literature review on the effects of digital transformation through AI, Blockchain, and IoT on dolphin choirresilience and sustainability are reliable and accurate, a quality assessment of the chosen studies was

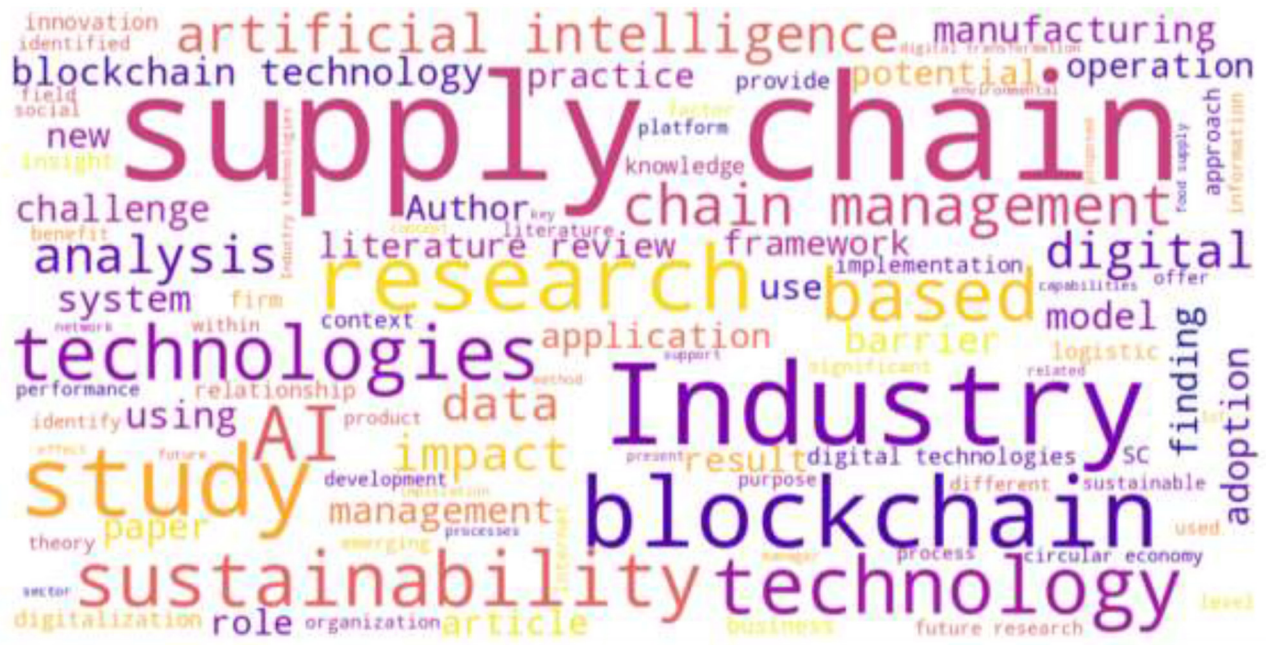

FIGURE 2
Word cloud. Source: Author.

necessary. This process involved a comprehensive evaluation of the methodological rigor, relevance, and overall impact of each study on our research objectives. Initially, studies were chosen based on their direct focus on digital transformation in supply chains and their implications for sustainability and resilience. Articles that addressed topics related to AI, Blockchain, and IoT in supply chain management were considered. The selected publications were subjected to a thorough quality evaluation utilizing present standards derived from accepted practices, like the PRISMA framework. The evaluation criteria centered on key features: quantitative studies were examined for their statistical analyzes, sample sizes, and control methods; qualitative studies were assessed for the coherence of their theoretical frameworks and the depth of their topic analyzes; and mixed-methods research was evaluated for its integration of quantitative and qualitative data. High-quality studies are defined as those that present novel insights, contest established paradigms, and deliver thorough evaluations that can guide strategic recommendations for practitioners and policymakers.

4 Results

Detailed flowcharts have been created to elucidate the study selection process in accordance with the PRISMA 2020 guidelines. Each stage of the review is illustrated in the flowchart, which specifies the number of records that are screened, excluded, and retained, from identification to final inclusion. Explicit reasons for exclusion are presented at each stage, such as the inability to retrieve full texts, insufficient methodological rigor, lack of relevance to the research question, or duplication. This inclusion improves the review's reproducibility and improves the transparency of the systematic exclusion of studies. The flowchart improves methodological clarity and enables future researchers to replicate or critically evaluate the rigor of the study selection process by documenting both the quantitative progression of records and the qualitative rationale for exclusions.

This study broadens the investigation to include digital transformation in supply chains through the integration of Blockchain and the Internet of Things (IoT). The review meticulously documents the records that are discovered, examined, and synthesized, thereby guaranteeing a rigorous and reproducible selection of high-quality literature. The objectives of this study are to assess the synergistic benefits of AI, Blockchain, and IoT, identify the challenges and opportunities that are inherent in their adoption, and develop strategic recommendations for practitioners and policymakers in the context of improving supply chain resilience and sustainability. The results improve both theoretical and practical comprehension.

The word cloud in Figure 2 visually illustrates the frequency of keywords in the literature that was assessed in this systematic literature review. The visualization emphasizes the critical terms that are essential for comprehending the adaptation of supply chains to the demands and opportunities of digital transformation. The study's significance is indicated by the prominent display of terms such as "Supply Chain", "Blockchain", "AI", and "Sustainability" in larger fonts in the word cloud. The literature primarily focusses on the importance of emerging digital technologies, with a particular emphasis on the impact of AI-driven analytics on the improvement of supply chain resilience and sustainability. "IoT", "Data", and "Traceability" are indicative of the increasing demand for transparency and visibility in real time throughout supply chains. Words like "resilience", "disruption", and "digital innovation" are used frequently, which emphasizes the

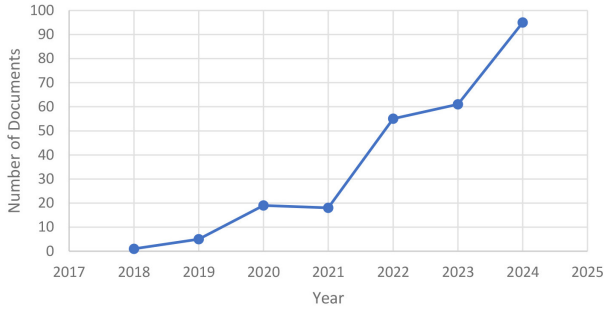

FIGURE 3
Documents by year. Source: Author.

importance of proactive tactics in navigating uncertainty. But the words "Barrier", "Complexity", and "Adoption" perfectly capture the difficulties and dynamic landscape involved in incorporating these digital solutions. The analysis of the word cloud reveals a rich and varied research environment, emphasizing the complex relationships between operational procedures, sustainability, and technology. The emphasis on AI-driven decision-making and blockchain-based transparency is indicative of a forward-thinking approach that recognizes the potential of digital technologies to transform supply chain outcomes.

The line graph in Figure 3 provides a comprehensive data visualization that effectively communicates the progression of research in digital transformation within supply chains from 2020 to 2024. The graph utilizes the *x*-axis to represent the years and the *y*-axis to indicate the annual count of academic publications, thereby enabling an immediate comprehension of the changing research productivity. The research output was relatively modest in the initial years of 2020 and 2021, as it was characterized by early exploratory studies and foundational investigations into the application of AI, blockchain, and IoT for supply chain improvement.

A gradual increase in 2022 indicates a growing recognition of the benefits and potential of these technologies to improve resilience and sustainability, as organizations began to address complex challenges such as data integrity, system interoperability, and operational efficiency. The most significant increase in publications was observed in 2023, which suggests a strong transition to practical implementation strategies and comprehensive research. This significant escalation is indicative of not only an expanded academic focus but also a response to global market pressures and disruptive events, which has prompted both industry and policymakers to prioritize digital transformation initiatives. The graph illustrates a trend that serves as a solid foundation for the development of strategic recommendations that are designed to effectively integrate digital technologies into supply chain management.

The bar graph in Figure 4 provides a comprehensive visualization of research publications on digital transformation in supply chains by country. The graph shows the total number of documents attributed to each country; the top-ranked country has 77 documents, while several others have as few as 10. This distribution makes it abundantly evident that research output varies greatly between regions, indicating that a small number of nations have developed strong research ecosystems that are probably strengthened by strong academic institutions, significant funding, and active private sector involvement in digital initiatives. Lower publication counts, on the other hand, might indicate new research hotspots or regions where supply chain digital transformation is just starting to take hold. The graph highlights the global disparity in scholarly focus, showing that some countries are leading the way in exploring supply chain management's integration of AI, Blockchain, and IoT, while others are still laying the groundwork for future studies in this area. This graphic representation not only draws attention to local advantages and strengths, but it also urges greater international cooperation to promote more equitable and inclusive development of resilient and sustainable supply chain methods.

The key data extracted from the systematic literature review on digital transformation in supply chains is comprehensively summarized in Table 1. It provides a comprehensive overview of the key characteristics of the chosen publications, such as the year of publication, research methodologies, and focal areas, including the integration of AI, Blockchain, and IoTs. The evolution of research on improving the resilience and sustainability of supply chains is illustrated through the meticulous curation of each entry to reflect the underlying trends and changes in scholarly focus over time. The table systematically organizes this information to highlight emerging patterns and significant insights, laying a strong foundation for the subsequent thematic analysis. Table 1 sets the stage for an in-depth examination of the challenges and opportunities that these technologies present by providing a clear snapshot of the current research landscape, thereby enabling readers to comprehend the context and scope of digital transformation initiatives within supply chain management.

5 Discussion

5.1 Theme one: integration of intelligence in SCM

The integration of automation and artificial intelligence (AI) into supply chain management (SCM) is a transformative force that improves sustainability and resilience. Predictive analytics is facilitated by AI technologies, which allow organizations to optimize resource allocation and anticipate disruptions. Various case studies have illustrated the strategic benefits of adopting digital transformation in logistics, as AI-driven insights enable decision-makers to effectively mitigate potential disruptions (Adama et al., 2024). Furthermore, Logistics 4.0 emphasizes the significance of AI in the transformation of supply chain processes, resulting in more efficient operations in a global market that is becoming increasingly interconnected (Vanoy, 2023). In addition to streamlining logistics, this integration also inspires a culture of innovation and continuous improvement within organizations (Ou, 2024).

The transformation of supply chain management (SCM) to digital is defined by the transition from conventional linear models to interconnected, data-driven ecosystems. This transformation

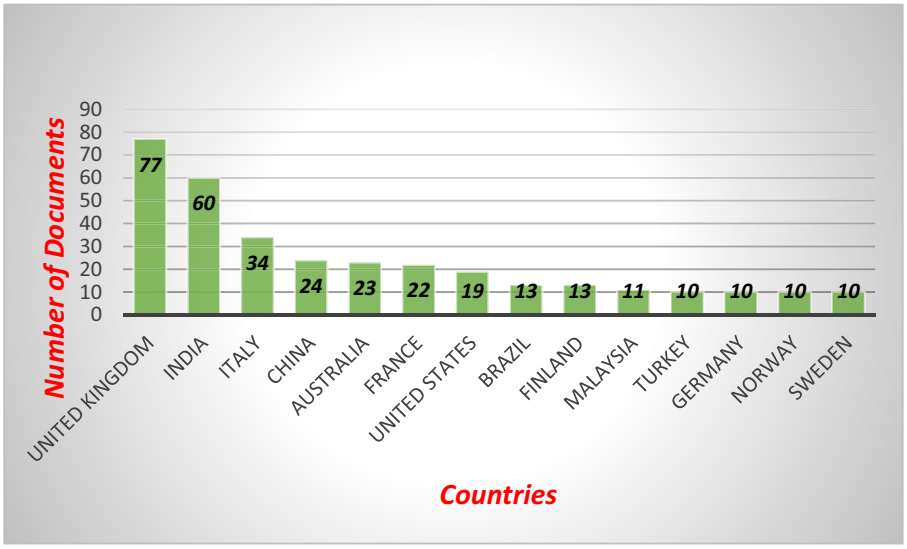

FIGURE 4
Documents by country. Source: Author.

enables agile decision-making and real-time visibility, which are essential for adjusting to the intricacies of contemporary supply chains (Reynolds, 2024). The integration of digital technologies, including the Internet of Things (IoT) and Blockchain, significantly augments this transformation by offering strong frameworks for data sharing and collaboration among supply chain partners (Stroumpoulis and Kopanaki, 2022). Organizations encounter challenges such as the integration of new technologies with existing systems and the maintenance of data security as they attempt to navigate this digital landscape (Sobb et al., 2020).

Nevertheless, these challenges are justified by the potential advantages, which include improved customer satisfaction and improved operational efficiency (Liang et al., 2023).

Effective supply chain management (SCM) practices are critically supported by decision tools and logistics. Organizations can make informed decisions in intricate logistics scenarios by analyzing vast amounts of data through the implementation of advanced decision support systems (DSS) (Kizielewicz and Sałabun, 2024). For example, logistics planning is increasingly incorporating simulation programs to optimize and visualize supply chain processes, thereby improving operational efficiency (Daroń, 2022). Furthermore, multi-criteria decision analysis (MCDA) tools are particularly beneficial in logistics, where trade-offs are frequent, as they enable decision-makers to assess a variety of alternatives based on conflicting criteria (Andrejić and Pajić, 2023). Not only does the integration of these decision tools improve logistical operations, but it also enables organizations to respond promptly to evolving market conditions, thereby contributing to the overall resilience and sustainability of supply chains (Oluyisola et al., 2021).

5.2 Theme two: human-centric industry 5.0

The synergy between human workers and automated systems is emphasized in Industry 5.0, where Human Automation Collaboration is a critical aspect. This collaboration is facilitated by the integration of AI and robotics in supply chains, which improves operational efficiency and decision-making processes. For example, Pflaum et al. (2021) emphasize that the implementation of robots and collaborative robots (cobots) can significantly improve process automation, thereby enabling human employees to concentrate on more strategic responsibilities that necessitate critical thinking and creativity. Additionally, Weisz et al. (2023) contend that AI has the capacity to independently determine actions that are consistent with supply chain objectives, thereby improving the overall efficacy of human-automation interactions. This partnership not only improves productivity but also cultivates a workforce that is more adaptable and capable of adapting to changing market conditions.

The digital transformation of supply chains, particularly in the era of Industry 5.0, is contingent upon the implementation of sustainable practices. It is imperative to implement digital technologies, including Blockchain, AI, and IoT, to improve the efficiency and transparency of sustainable supply chain management.

As Chen (2024) emphasizes, these technologies have the potential to significantly improve supply chain transparency, a critical component of sustainable practices. Pyun and Rha (2021) further assert that sustainability is a critical factor in the transformation of supply chain strategies and business models, emphasizing the importance of digital transformation for sustainable viability. This notion is further substantiated by the empirical evidence presented by Yuan et al. (2023), which demonstrates that digital transformation has a direct impact on supply chain resilience, a critical component of sustainability. Organizations can not only improve their operational efficiency but also contribute to more extensive environmental objectives by incorporating these technologies.

Industry 5.0 is distinguished by the concept of a Bionic Supply Chain, which integrates advanced technologies with human intelligence. Digital technologies are employed in this method to establish a supply chain that is more resilient

TABLE 1 Main themes, subthemes, and short quotes.

Main theme	Subtheme	Short quote
Integration of intelligence in SCM	AI and automation	"Integrating Intelligence and Sustainability in supply chains is vital for future competitiveness."—Bentalha et al. (2023)
		"The growth of digital technologies and Artificial Intelligence (AI) has the potential to increase global efficiency."—Michael (2024)
		"AI and machine learning are revolutionizing SCM with automation."—Chou (2024)
		"Emerging technologies have become key for practical application of AI in SCM."—Sodhi et al. (2022)
	Digital transformation	"Digital technologies are reshaping the landscape of supply chain management."—Chase (2016)
		"Industry 4.0 aims to significantly improve SCM processes."—Fatorachian and Kazemi (2020)
		"Data produced at an unprecedented speed is transforming SCM."—Lechler et al. (2019)
		"The logistics industry is adapting to technological advancements."—Krishnan et al. (2024)
	Decision tools and logistics	"Decision tools are key for improving reverse logistics in the circular economy."—Mallick et al. (2024)
		"Supply Network 5.0 improves decision-making in SCM."—Mohamed et al. (2023)
		"Optimized decision tools are key in sustainable SCM."—Taticchi et al. (2015)
		"Innovative decision tools improve efficiency in logistics."—Cherchata et al. (2022)
Human-Centric Industry 5.0	Human automation collaboration	"How to improve human automation collaboration in Supply Network 5.0."—Nicoletti (2023)
		"Human-centric technologies are key in Industry 5.0."—Nahavandi (2019)
		"Collaboration between humans and automation improves SCM."—Hoberg et al. (2020)
		"Bionic supply chains encourage better human-automation interaction."—Nicoletti (2023)
	Sustainable practices	"Responsible Industry 4.0 emphasizes a framework for human-centric technology."—Arora et al. (2024)
		"Sustainable practices are integrated within human-centric SCM."—Juned et al. (2025)
		"Industry 5.0 drives sustainability in SCM."—Juned et al. (2025)
		"AI innovation supports sustainable practices in SCM."—Belhadi et al. (2024)
	Bionic supply chain	"Examining the impact of a bionic supply chain on digital transformation."—Grebe et al. (2020)
		"Bionic supply chains incorporate advanced digital tools."—Grebe et al. (2020)
		"Human-centric bionic supply chains improve operational efficiency."—Yang et al. (2024)
		"Bionic supply chains are pivotal in modern SCM."—Dubgorn et al. (2021)
Challenges in digital supply chains	Interoperability	"Ensuring interoperability across digital platforms remains a major challenge in Industry 5.0."—Maddikunta et al. (2022)
		"Complex system integration is essential for seamless data exchange in advanced supply chains."—Yasmin (2024)
		"The success of Industry 5.0 hinges on interoperable technologies that unify diverse processes."—Patil et al. (2024)
		"Without common standards, digital transformation faces significant interoperability barriers."—Barbu et al. (2024)
	Skills and training	"Continuous skill development is paramount for sustaining digital innovation in supply chains."—Foroughi (2021)
		"The shift to Industry 5.0 demands reskilling of the workforce to handle collaborative automation."—Islam et al. (2025)
		"Employees trained in digital tools drive faster adoption of advanced supply chain solutions."—Foroughi (2021)
		"Ongoing training initiatives mitigate resistance to new technologies in Industry 5.0."—Sarkar et al. (2024)
	Policy and regulation	"Effective regulations promote ethical and secure deployment of Industry 5.0 technologies."—Arputharaj et al. (2024)
		"Supportive policies can accelerate the widespread adoption of digital innovations in supply chains."—Attaran (2020)
		"Governments must establish clear guidelines to ensure responsible data handling in Industry 5.0."—Arputharaj et al. (2024)
		"Well-defined regulatory frameworks reduce uncertainties and encourage investment in advanced SCM."—Setino (2018)

and responsive. Liang et al. (2023) have observed that the implementation of smart supply chains that are based on digital technologies improves the overall coordination and response capacity of firms, thereby allowing them to manage disruptions more effectively. Additionally, the research conducted by Yang et al. suggests that the implementation of digital technologies is essential for the improvement of supply chain capabilities and competitive performance, thereby emphasizing the significance of a bionic approach (Yuan et al., 2023). Zhao et al. (2022) emphasize that the integration of AI, IoT, and Blockchain not only enables real-time data sharing and decision-making, but

also promotes innovation within the supply chain. They discuss how digital transformation can drive enterprise innovation. A supply chain that is more agile and resilient, capable of adapting to changing market demands, is the ultimate result of this bionic approach.

5.3 Theme three: challenges in digital supply chains

Digital supply chains face a significant challenge in the form of interoperability, which is the seamless integration of various systems and technologies. If improperly managed, the integration of numerous digital tools can result in significant inefficiencies. As an illustration, the absence of standardization in digital technologies can impede the attainment of complete visibility throughout the supply chain, particularly for small and medium-sized enterprises (SMEs) that may lack the requisite digital capabilities. Additionally, the integration of a variety of technologies necessitates the development of strong data-sharing platforms that can facilitate communication between various systems, a capability that is frequently absent in conventional supply chain configurations (Yerpude et al., 2022). The concept of a digital supply chain twin, which offers real-time visibility and synchronization throughout the supply chain, emphasizes the significance of interoperability in improving supply chain performance (Kegenbekov and Jackson, 2021).

Skills and Training are essential for overcoming the challenges presented by digital transformation in supply chains. There is an urgent need for workforce development to guarantee that employees have the requisite skills to effectively utilize advanced technologies as organizations adopt them. Research suggests that the performance of the overall supply chain can be significantly improved by training programs that are specifically designed to improve the digital capabilities of suppliers (Singh, 2024). Additionally, organizations must undergo a cultural transformation during the digital transformation process, which involves the integration of continuous learning and adaptation into their operations (He et al., 2024). The significance of investing in training and development initiatives is emphasized by the fact that the successful implementation of digital technologies is frequently contingent upon the workforce's capacity to adapt (He et al., 2024).

The landscape of digital supply chains is also significantly influenced by Policy and Regulation. Kimwaki et al. (2022) emphasize that the rapid pace of technological advancement frequently surpasses the capacity of existing regulatory frameworks, resulting in a gap that can impede effective implementation. Policymakers must establish regulations that not only facilitate the adoption of digital technologies but also address ethical, security, and data privacy concerns in supply chain management (Stroumpoulis and Kopanaki, 2022). The alignment of industry standards and regulations is crucial for the promotion of interoperability and the guarantee that all stakeholders can engage in the digital supply chain ecosystem (Fatorachian and Kazemi, 2020). Clear guidelines can be established to mitigate risks associated with digital transformation and cultivate an environment that is conducive to collaboration and innovation (Hejazi et al., 2023).

Despite the significant potential of digital technologies like AI, Blockchain, and IoT, their implementation is frequently hindered by complex challenges that necessitate more in-depth analysis. Inefficiencies and costly integration failures are the result of interoperability challenges that arise because of fragmented standards and heterogeneous legacy systems, as demonstrated by SMEs that encounter difficulties in aligning blockchain platforms with existing enterprise systems (Alimohammadlou and Alinejad, 2025). The vulnerability of IoT-enabled supply chains to network intrusions has been demonstrated by Shafik (2025), who have also substantiated cybersecurity risks through empirical studies. This vulnerability frequently leads to significant financial losses and reputational damage. Foroughi (2021) observes that firms encounter not only high training costs but also cultural resistance to change, which delays adoption and contributes to project delays, which is another structural challenge presented by workforce upskilling. Case evidence also emphasizes that high-profile blockchain pilots in logistics have failed because of the inability to demonstrate clear value in early phases and prohibitive operational costs (Bhandari, 2024). In addition to financial and technical constraints, ethical considerations necessitate equal consideration. Sustainability dilemmas that cannot be disregarded include the significant energy footprint of blockchain consensus mechanisms, cross-border data governance, and data privacy in IoT-driven supply chains (Arputharaj et al., 2024). The alignment of technical innovation with strong governance, cost-benefit analysis, and ethical safeguards is essential for a comprehensive response to these challenges. This will ensure that digital transformation initiatives genuinely advance resilience and sustainability without generating new forms of vulnerability.

5.4 Proposing a conceptual model: building a resilient supply chain

The comprehensive framework for constructing a resilient supply chain is illustrated in Figure 5. It emphasizes six critical components: AI integration, IoT implementation, blockchain, human-centric collaboration, training and skills, and policy and regulation, that work together to improve the overall resilience of the supply chain. Artificial intelligence integration offers organizations the ability to anticipate disruptions, allocate resources more efficiently, and streamline decision-making processes by providing predictive insights and optimisation capabilities. The implementation of IoT technologies improves AI by providing real-time visibility into operations through sensor data, which can be analyzed to implement immediate corrective measures. Meanwhile, blockchain technology introduces transparency and traceability, thereby facilitating secure data exchange and reinforcing trust among supply chain partners. The technological foundation that supports a future-oriented, resilient supply chain is composed of these three pillars.

Human-centric collaboration, training and skills, and supportive policy and regulation are equally essential for the development of a resilient ecosystem, in addition to technology.

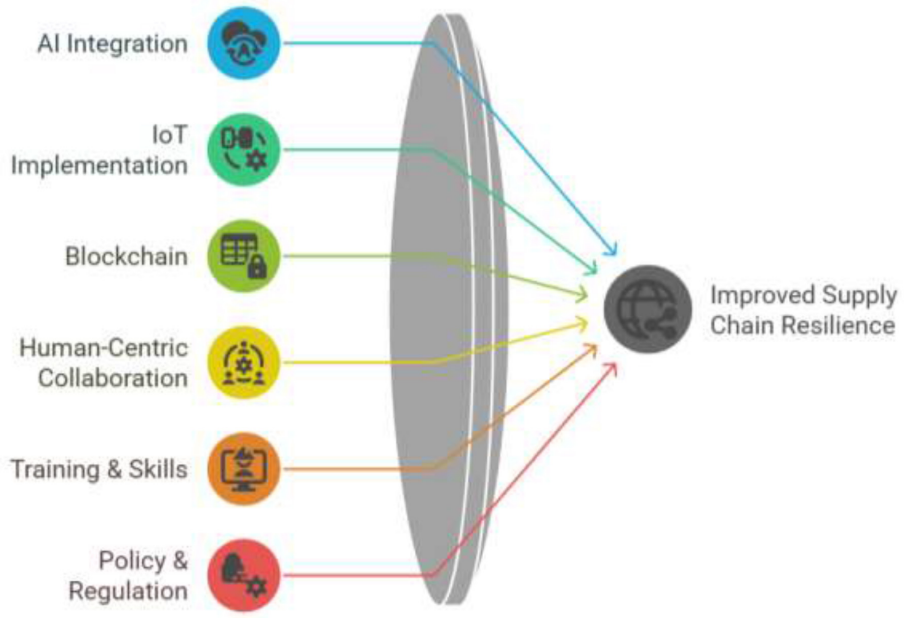

FIGURE 5
Building a resilient supply chain. Source: Author.

Human-centric collaboration emphasizes the importance of effective communication, stakeholder engagement, and cultural alignment in supply chain management, with a particular emphasis on the human element. The knowledge and competencies necessary to operate and adapt to emerging technologies are ensured by training and skills development for employees and leaders. Lastly, the ethical, legal, and social dimensions of supply chain operations are regulated and governed by policy and regulation, which establishes standards that protect environmental responsibility, consumer trust, and data integrity. Organizations can establish adaptive, sustainable, and strong supply chains that can withstand global disruptions and rapidly changing market demands by achieving a balance between technological advancement and human and regulatory factors. An integrated approach is essential for achieving improved supply chain resilience, as evidenced by the interaction of these six elements.

5.5 Theoretical and practical implications

The theoretical and practical implications of the integration of AI, Blockchain, and IoT in supply chains are significant for both managers and policymakers. Our research theoretically contributes to the academic discourse on digital transformation by demonstrating the way these technologies interact to improve the sustainability and resilience of the supply chain. It provides a framework that elucidates the mechanisms behind real-time data analytics, improved traceability, and risk mitigation, thereby establishing a foundation for future research on the digital evolution of supply chains. The results are a practical guide for supply chain managers, encouraging them to invest in advanced digital infrastructures and workforce training to effectively leverage these technologies. The study emphasizes the necessity of regulatory frameworks that prioritize ethical considerations, interoperability, and data security for policymakers. Collectively, these insights assist in bridging the gap between academic theory and real-world application, providing stakeholders with strategic recommendations to transform conventional supply chains into sustainable, agile networks that can withstand global disruptions.

5.6 Limitations

Digital transformation in supply chains through AI, Blockchain, and IoT presents numerous challenges and constraints that may impede successful implementation. A significant challenge is the significant initial investment necessary for infrastructure upgrades and technology integration, which can be especially burdensome for small and medium-sized enterprises. Furthermore, interoperability issues that disrupt the seamless exchange of data are frequently caused by the lack of compatibility between legacy systems and newer digital platforms. The implementation process is further complicated by data privacy and cybersecurity risks, which undermine stakeholder trust by making sensitive supply chain information susceptible to breaches and cyber-attacks. The continuous upskilling of the workforce is also required due to the rapid pace of technological advancement, which places an additional strain on resources and necessitates ongoing investment in training programs.

Additionally, the adoption of innovative solutions can be hindered by established processes and cultural inertia, as organizational resistance to change continues to be a significant

challenge. Another layer of complexity is introduced to the transformation journey by regulatory uncertainties regarding data protection, cross-border data flows, and ethical considerations. These challenges emphasize the necessity of a collaborative effort among policymakers, technology providers, and industry leaders to establish strong standards, effective training frameworks, and supportive regulatory environments that can reduce risks and encourage the sustainable evolution of supply chain management.

6 Conclusion and recommendations

The transformative potential of integrating AI, Blockchain, and IoT within supply chains to improve resilience and sustainability is emphasized by the primary findings of this research. The study demonstrates that these digital technologies improve operational efficiency through real-time monitoring, predictive analytics, and secure data sharing, thereby minimizing disruption risks and optimizing resource allocation. Secondly, the study emphasizes the significant contribution of digital transformation to the promotion of transparency and traceability, which are essential components of stakeholder trust and the maintenance of compliance with changing regulatory standards. The third finding is that the findings identify persistent challenges, including high implementation costs, heightened cybersecurity risks, and interoperability issues with legacy systems, which can impede the seamless adoption of these innovations.

Furthermore, the study demonstrates the importance of adaptive organizational cultures that prioritize change and continuous workforce upskilling to guarantee the effective utilization of digital tools. The practical implications of these findings are of great importance: supply chain managers are encouraged to strategically invest in digital infrastructure and training, while policymakers are urged to develop strong regulatory frameworks that support innovation without compromising data integrity and security. The study ultimately offers a comprehensive roadmap for digital transformation, emphasizing both the transformative benefits and the challenges that must be overcome to establish sustainable and resilient supply chains in a global market that is rapidly evolving.

To improve the sustainability and resilience of the supply chain, industry practitioners should implement a phased digital transformation strategy that seamlessly integrates AI, Blockchain, and IoT. Organizations must initially evaluate their current systems and pinpoint the areas in which these technologies can produce the most significant improvements. It is imperative to upgrade IT infrastructures and guarantee interoperability between modern digital platforms and legacy systems. Real-time data sharing and improved decision-making processes will be facilitated by the implementation of standardized data protocols. To further strengthen stakeholder trust, strong cybersecurity measures must be given top priority to protect sensitive supply chain data.

Additionally, it is imperative to cultivate a culture of perpetual learning. To this end, the development of targeted training programs is necessary to promote cross-functional collaboration between IT and supply chain management teams and to improve digital literacy among employees. Additionally, innovation and the exchange of best practices can be expedited by engaging with technology providers and participating in industry consortiums. Finally, to advance sustainability, practitioners should implement AI-driven predictive analytics to predict disruptions, implement blockchain technology to improve traceability and accountability, and implement IoT for real-time monitoring to optimize resource allocation and minimize waste. These strategic recommendations provide a comprehensive roadmap for the development of environmentally responsible, resilient, and agile supply chains.

The existing literature synthesis reveals the potential of digital transformation in supply chains, as well as persistent gaps that should inform future research. First and foremost, the reliance on cross-sectional or conceptual approaches in prior studies is a clear limitation, as it restricts the comprehension of the long-term impact of digital tools on sustainability and resilience. Future research should incorporate time-series analysis, latent growth modeling, and periodic panel surveys to capture long-term trajectories, in addition to longitudinal and mixed-methods designs, to address this issue. Secondly, the literature is primarily composed of evidence from developed economies, which creates a contextual gap in the comprehension of the functionality of AI, Blockchain, and IoT in developing countries. These countries face unique challenges due to infrastructure limitations, regulatory uncertainty, and resource constraints. To ensure that empirically grounded, context-sensitive insights are provided, comparative case studies across regions and organizational sizes are necessary.

Third, most of the reviewed studies are devoid of rigorous empirical testing, frequently relying on small-scale case illustrations or theoretical models. Future research should therefore implement strong methodologies that integrate qualitative depth with large-scale quantitative analyzes, such as simulation modeling and scenario testing, to assess the effectiveness of implementations in a variety of scenarios. Lastly, this review emphasizes the importance of cybersecurity, interoperability, and workforce skills. However, empirical studies have yet to address ethical considerations, including data privacy, algorithmic bias, and the environmental impact of blockchain. These ethical dimensions must be addressed to guarantee that digital transformation contributes to responsible and resilient supply chains. Scholarship can progress from broad recommendations to the development of evidence-based, globally relevant strategies for sustainable supply chain transformation by explicitly connecting future agendas to these observed gaps.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

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