IJSOM International Journal of Supply and Operations Management

Blockchain Technology Adoption for Resilient Supply Chains: Systematic Literature Review

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Article Info

Article type:
Review Article

Article history:
Received May 24, 2026
Received in revised form July 30, 2026
Accepted August 20, 2026
Available online August 28, 2026

***Keywords*:**
blockchain
resilient supply chain
systematic literature review
critical success factors
challenges

ABSTRACT

Objective: This study conducts a systematic literature review to explore the adoption of blockchain technology in fostering resilient supply chains, aiming to guide decision-makers by highlighting existing research gaps, challenges, and critical success factors.

Methods: Following a predefined protocol, 71 articles published between January 2019 and June 2026 were collected from Scopus and Web of Science and analyzed descriptively. The scope is limited to English-language articles indexed in the selected databases.

Results: The findings are grouped into three areas: critical success factors such as trust, smart contracts, traceability, and transparency; challenges including scalability, complexity, and limited industry acceptance; and resilience strategies involving supply chain re-engineering, enhanced collaboration, and improved agility. The review also reveals research gaps in technological developments and conceptual frameworks, and highlights under-explored technologies, namely oracles, cross-chain interoperability, zero-knowledge proofs, and secure multi-party computation.

Conclusion: The results provide valuable direction for future research. Academics can build on these insights to address uncovered gaps, while practitioners may apply the identified success factors and resilience strategies to implement blockchain solutions that foster adaptability, trust, and efficiency in dynamic supply chain environments.

Cite this article: Fallahpour, M., Safaei Ghadikolaei, A., Fallah Lajimi, H., & Arab, A. (2026). Blockchain Technology Adoption for Resilient Supply Chains: Systematic Literature Review. *International Journal of Supply and Operations Management*, *XX*(X), pages. https://doi.org/10.22034/ijsom.2026.110837.3425

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Publisher: Kharazmi University
DOI: https://doi.org/10.22034/ijsom.2026.110837.3425

1. Introduction

The supply chain has faced significant challenges due to the COVID-19 pandemic, natural disasters, and other disruptions, resulting in production delays, increased costs, and reduced performance, particularly in global manufacturing networks (Akram et al., 2024; Meyer et al., 2023; Niu et al., 2022). These challenges often lead to delays in transporting goods, communication breakdowns with suppliers, lower product quality, and higher costs (Lai et al., 2021). Therefore, it is crucial for supply chain managers to effectively identify, assess, and mitigate these disruptions to maintain the stability and resilience of their supply chains (Azmi et al., 2022). Historically, organizations practiced risk management by anticipating and preparing for threats that were already identified and known. These approaches focused on identifying potential risks and developing strategies to address them. For example, companies would buy comprehensive insurance policies to minimize financial losses that could result from an impending disaster. This was practically useful at a time when the business environment was relatively stable, with fewer variables in play. However, as global supply chains have become increasingly intricate, they have posed new challenges for businesses. In the last few decades, the world has seen global financial crises, severe climate changes, wars, pandemics, and rapid technological improvements, all of which have the capacity to significantly disrupt the global supply chain (Fiksel, 2006).

Resilience goes beyond merely recovering from disruptions. It involves a system's ability to adapt, learn, and emerge stronger. In other words, while traditional risk management focuses on damage reduction, resilience seeks to turn threats into opportunities (Min, 2019). An essential characteristic of resilience is the focus on preparing for crises and recovering from them by actively learning from experience, rather than simply avoiding them. This attitude permits greater flexibility and adaptability with respect to the anticipated future. For instance, the impact of a crisis is buffered by adaptive capabilities. Resilient organizations do not just bounce back to the pre-crisis state; they use the insights gained during the crisis to fortify themselves and build further competitive edges (Fiksel & Fiksel, 2015).

In today's volatile global environment, advanced technologies are increasingly recognized for their effectiveness in addressing supply chain challenges. Among these solutions is blockchain technology, which provides visibility and security for data storage and serves as a platform (Beck et al., 2023; Liu et al., 2024). Using blockchain, all supply chain stakeholders can access details on production, shipping, and distribution. Crucially, this data remains unchanged, ensuring the accuracy of the information (Singh et al., 2023). Furthermore, blockchain technology (BT) helps reduce operational costs by removing the need for intermediaries, thus simplifying and streamlining supply chain processes (Li et al., 2023). As a result, managers can enhance the efficiency and cost-effectiveness of their supply chain operations. Another notable benefit of blockchain technology is its ability to provide real-time, precise tracking of products throughout their journey through the supply chain (Hu et al., 2024). By providing timely information on production, transportation, and distribution processes, blockchain enables supply chain managers to proactively address issues and make well-informed decisions, ensuring a smooth flow of goods without disruptions or delays (Singh et al., 2023). Given its advantages, blockchain can play an important role in supply chain resilience by providing accurate process tracking. It enables managers to respond more quickly to crises, identify vulnerable points, and take timely corrective actions. Additionally, the immutability of blockchain data reduces fraud and increases credibility among partners, contributing to overall supply chain resilience (SCRES) (Min, 2019).

Although a growing body of literature has examined the role of blockchain technology in supply chains, significant gaps remain in understanding its full potential for enhancing supply chain resilience. Most existing studies concentrate on basic features. Far less attention has been paid to more advanced blockchain capabilities that could address complex, multi-dimensional resilience challenges, including real-time data integration from external sources, interoperability across different blockchain platforms, privacy-preserving verification, and secure collaborative computation among untrusted parties. This narrow focus has left important questions unanswered regarding how blockchain can support the entire resilience cycle — from disruption detection and response to long-term recovery and adaptation. As a result, current knowledge remains fragmented and provides limited practical guidance for organizations seeking to build truly resilient supply chains in increasingly volatile environments.

Although recent systematic reviews have addressed the intersection of blockchain and supply chain resilience (Beck et al., 2023; Singh et al., 2023), several important gaps remain. Beck et al. primarily linked blockchain characteristics to resilience antecedents and risk types, while Singh et al. focused more broadly on secured and cyber-resilient supply chains. The present review extends this body of work by offering a more recent corpus and a structured analysis of critical success factors and challenges.

By addressing these questions, the study aims to expand current knowledge and provide new insights into how blockchain technology can support the development of resilient supply chains:

RQ1: What are the major themes in the growing field of blockchain applications in resilient supply chains?

RQ2: What are the knowledge gaps and limitations in existing literature, and what future research opportunities can be explored to advance this field?

2. Theoretical Foundations

2.1 The Concept of Resilience

The study of resilience in systems engineering has gained prominence in recent years. In this regard, resilience includes greater adaptive functional capability designed into the systems, going beyond dependability (Moskalenko et al., 2023).

Since 2005, system resilience has received increasing attention, with definitions emerging. Resilience, as defined by Allenby and Fink (2005), refers to a system's ability to maintain its operations and underlying structure while undergoing external change and controlled decline when needed. Haimes (2009) defines resilience as the ability of a system to bear disturbances, control degradation to acceptable levels, recover within a reasonable time, and balance costs and risks. Cimellaro et al. (2010) describe it as the ability of a given system to maintain functionalities and recover from disruptions. According to Yodo and Wang (2016), resilience refers to detecting and withstanding functional change, failure, and recovery. They formulate resilience as the ability to adapt to changes, endure disruptions, and recover. Overall, resilience enhances a system's adaptive capacity under disruption (Sadegheih & Dayani Dardashti, 2025).

Supply chain resilience is the ability to maintain and recover from disruptions in the supply chain on time. To increase resilience, flexibility, redundancy, and collaboration need to be improved, and swift action must be enabled. Different models and criteria are being developed to refine the evaluation and management of SCRES, focusing on policies that capture the entire supply chain's characteristics (Purvis et al., 2022). The dynamic capabilities perspective and simulation models complement these. The key aim is to provide functionality and effective adaptation to changes across the various portions of the supply chain (Kochan & Nowicki, 2018; Ponomarov & Holcomb, 2009; Tukamuhabwa et al., 2015).

In the concept of a resilient supply chain, eight stages were presented by Sheffi and Rice Jr (2005), which are specified in Table 1 and Figure 1.

Table 1. Stages of resilient supply chain

Stage	Definition
Preparation	This first stage includes actions and strategies implemented before the event.
Disruptive event	This phase signifies the event's occurrence, whether a calamity, a supply chain disruption, or any unforeseen incident that impacts regular operations.
First response	In the reaction, the focus is on managing the situation, safeguarding lives, deactivating impacted systems, and averting harm.
Initial impact	After a major incident occurs and the initial response is underway, companies begin evaluating the impact on their activities, systems, and those involved. This phase includes examining the harm caused and understanding the extent of the disturbance.
Full impact	Whether it happens away, takes some time before the full effect kicks in, or performance tends to decrease rapidly.
Recovery preparations	Recovery preparations usually begin alongside the response. Sometimes, even before the disruption, it is expected. This includes assessing suppliers and reallocating suppliers' resources.

Stage	Definition
Recovery	Many businesses aim to return to their previous productivity levels by increasing capacity, using overtime, and leveraging resources from suppliers and customers.
Long-term impacts	Recovering from disruptions usually takes time. When customer relationships suffer, the effects can linger and prove challenging to mend.

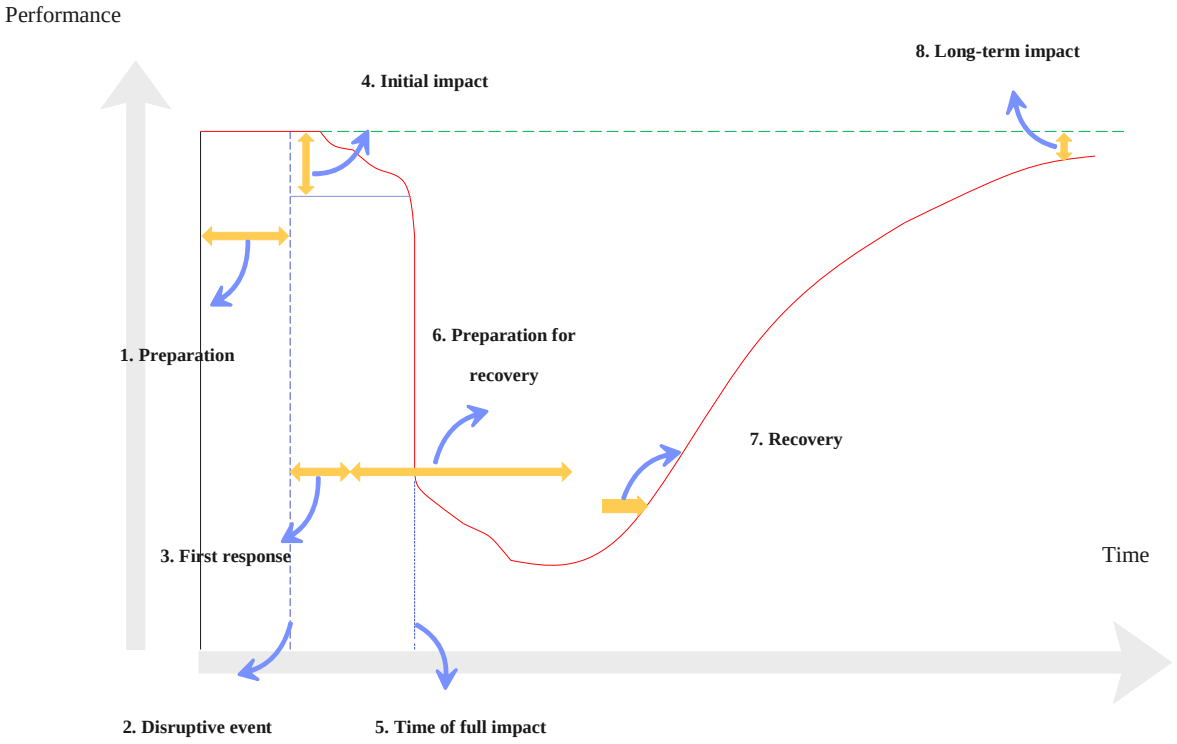


Figure 1. Stages of resilient supply chain

2.2 Blockchain in the Resilient Supply Chain

The foundation of Bitcoin Blockchain Technology was publicized in 2008 by Satoshi Nakamoto, who virtually combined the ideas of currencies with the principles of cryptography, creating a public ledger that showcases "Bitcoin" transaction history (Mukherjee & Pradhan, 2021). Each block includes a cryptographic hash, a timestamp, and the hash of the preceding block, creating an immutable chain that ensures the integrity, security, and reliability of the blockchain ledger (Nasiri-Galeh & Sahraei, 2024). Over the years, this technology has evolved through five distinct stages (Figure 2). The journey of blockchain commenced with the Introduction of Bitcoin as a cryptocurrency, the starting point for financial transactions, which was known as Blockchain 1.0 (Choi & Siqin, 2022). Later, with the introduction of Smart Contracts, came the Blockchain 2.0 era. These allowed individuals to execute preprogrammed commands or run specific logic without an intermediary (Leng et al., 2020).

Soon after, Blockchain had to grow to become a worldwide peer-to-peer network, leading to its evolution into Blockchain 3.0. This phase sought to maintain a high level of openness and security. At this point, all users of the Blockchain could autonomously verify that the information stored was accurate, permanently fixed, and not controlled by any dominant entity (Bai & Sarkis, 2020). Phase 4 marked the point where blockchain technology entered the real world. Business operations such as supply chains, logistics, healthcare systems, and energy management actively use

blockchain technology. Instead of being an idea, blockchain became a tool that improved our everyday lives (Dutta et al., 2020). The advent of Blockchain 5.0 was marked by the incorporation of emerging technologies such as machine learning, artificial intelligence (AI), the Internet of Things (IoT), and data analytics. At this stage, blockchain technology has transformed from an automated tool to an intelligent system. Today, blockchain technology can autonomously identify problems, optimize processes, and enable businesses to make data-based decisions. This generation of blockchain technology has transformed various industries with the development of smart applications (Choi & Siqin, 2022).

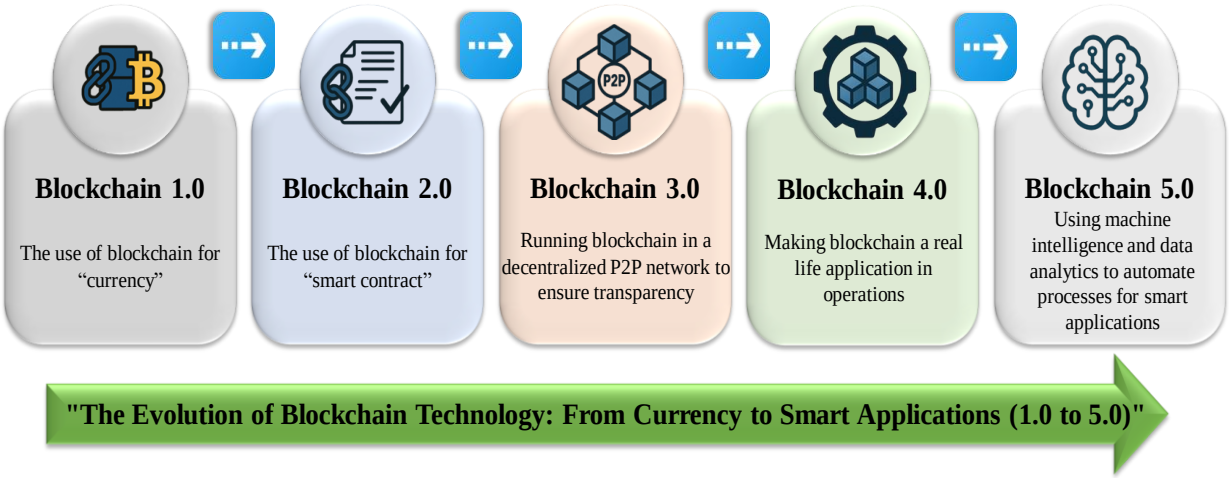


Figure 2 . The evolution of blockchain technology (Author's own work)

Blockchain is used widely in various sectors, like energy trading systems (Wang et al., 2019; Yang & Yin, 2023), supply chain (Shemov et al., 2020), smart mobility data markets (Lopez & Farooq, 2020), port logistics capability (Wang et al., 2021), supply chain finance solution (Li et al., 2020), Agri-food (Cruz & De Arruda, 2023), transport logistics (Boateng & Asante, 2026), dairy industry (Ghiasabadi et al., 2025) and medical systems (Du et al., 2020; Gong & Zhao, 2020; Połap et al., 2021).

Blockchain technology is a decentralized, distributed ledger-based infrastructure that provides secure, transparent, and traceable data and transaction management while ensuring data integrity and accessibility (Hasheminezhad et al., 2026). These capabilities enable blockchain to address critical challenges in traditional supply chain systems and significantly enhance supply chain management (Queiroz et al., 2020). By providing a decentralized and immutable ledger, blockchain enables real-time tracking and tracing of products, reducing the risk of fraud, counterfeiting, and errors (Longo et al., 2019). Moreover, the adoption of smart contracts automates contractual agreements, streamlining processes and reducing administrative burdens (Dutta et al., 2020). Besides speeding up transaction processing, this automation also reduces transaction costs and increases efficiency. Blockchain also enables easier data access and synchronization among supply chain participants, increasing collaboration and decision-making (Francisco & Swanson, 2018).

The increasing frequency of supply chain disruptions underscores the importance of companies prioritizing resilience to address challenges effectively and promptly (Lohmer et al., 2020). Companies enhance their resilience by implementing excellent practices and leveraging supply chain capabilities such as collaboration, flexibility, visibility, and speed. Blockchain technology enhances the resilience of the supply chain by safeguarding against cyberattacks, malware, server issues, network failures, fraud, and human errors (Singh et al., 2023). By leveraging features such as immutability, traceability, efficiency, and transparency, blockchain enhances the supply chain's ability to maintain reliability among members, thereby improving efficiency (Mubarik et al., 2023). Businesses utilize supply chains to monitor the transportation of their goods or resources. However, issues such as origins, information visibility, and credibility concerns persist in the supply chain (Gupta et al., 2023; Pandey et al., 2024). Recognizing the connection

between disruption management and traceability in this digital age, traceability is crucial for enhancing supply chain resilience (Akram et al., 2024; Mishra et al., 2022). Blockchain technology, as an emerging innovation, can be seamlessly integrated into the supply chain to address challenges and enhance its efficiency (Akhavan & Philsoophian, 2023; Pal, 2023). The ability to adapt, respond swiftly, and maintain alignment is essential to a supply chain. Agility refers to a company's capacity to adjust to market fluctuations promptly (Beck et al., 2023; Li et al., 2023).

3. Methodology

The current research uses one of the most reliable and widely used approaches to systematically review the literature in this field, as presented by (Carrera-Rivera et al., 2022). In general, the research framework is structured as follows (Figure 3):

Phase 1: Planning

Step 1: Determining research objectives and questions

Step 2: Selecting the digital library source

Step 3: Introducing theories and concepts

Phase 2: Collecting and Analyzing Qualitative Research

Step 4: Building digital library strings

Step 5: Excluding duplicates

Step 6: Evaluating inclusion and exclusion criteria

Step 7: Selecting papers

Phase 3: Analysis

Step 8: Data extraction

Step 9: Answering the research questions

Step 10: Future study suggestions

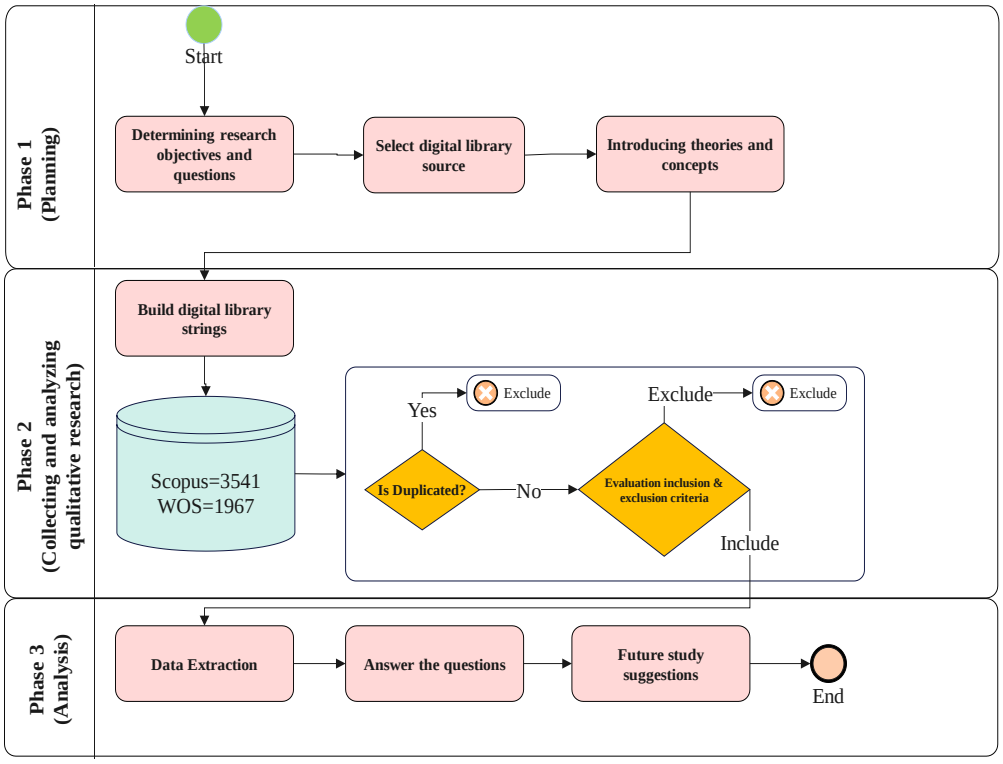


Figure 3. Research framework (Author's own work)

The researchers implemented a systematic review approach to answer the study's research questions by identifying, evaluating, and interpreting relevant research papers. This section explains how the review was conducted. Articles were initially gathered from Scopus and Web of Science, covering the period from 1 January 2019 to 10 June 2026. The literature search was conducted in the Title, Abstract, and Keywords fields of both databases using database-specific Boolean search strings. The search strategy combined three groups of keywords related to blockchain technology, supply chain, and resilience, linked by Boolean operators to retrieve studies that address their intersection. Minor adjustments were made to accommodate the syntax requirements of each database while preserving the same search logic. The complete search strings used for Scopus and Web of Science are presented in Table 2.

Table 2. Keywords used in Scopus and WOS

Database	Search String
Scopus	TITLE-ABS-KEY: (blockchain OR "smart contract" OR "distributed ledger" OR cryptocurrency OR ethereum) AND ("supply chain" OR "supply chain management" OR "supply chain performance") AND (resilien* OR disrupt* OR crisis OR vulner* OR risk)
Web of Science	Topic: (blockchain OR "smart contract" OR "distributed ledger" OR cryptocurrency OR ethereum) AND ("supply chain" OR "supply chain management" OR "supply chain performance") AND (resilien* OR disrupt* OR crisis OR vulner* OR risk)

4. Systematic Literature Review

4.1 Step One: Material Collection

This study employs a Systematic Literature Review (SLR) approach based on the guidelines proposed by Carrera-Rivera et al. (2022). The review process followed three main phases: Planning, Data Collection and Screening, and Analysis and Synthesis, as shown in Figure 3. A comprehensive literature search was conducted in Scopus and Web of Science (WOS), two globally recognized databases that provide extensive coverage of high-quality peer-reviewed publications across management, engineering, and technology disciplines. These databases were selected because of their broad journal coverage, rigorous indexing standards, citation analysis capabilities, and widespread use in systematic literature reviews, thereby enhancing the visibility, reliability, and reproducibility of the review process (Pranckutė, 2021).

Necessary adjustments were made to comply with each database's syntax requirements (e.g., field codes and year filters). In Scopus, the search was limited to articles and book chapters. The same restrictions were applied in Web of Science. To ensure relevance and quality, the following criteria were applied. Inclusion Criteria: 1- Peer-reviewed journal articles and book chapters published in English. 2- Studies addressing blockchain technology in the context of supply chain resilience, risk management, and disruption. 3- Papers published between 1 January 2019 and 10 June 2026. 4- Studies providing insights on critical success factors, challenges, strategies, or technological aspects of blockchain in resilient supply chains. Exclusion Criteria: 1- Non-English language publications. 2- Conference papers, editorials, letters, notes, and preprints. 3- Studies focused solely on blockchain or supply chain without linking both topics. 4- Papers with insufficient empirical or conceptual contribution to the research questions. The complete screening and selection process is illustrated in Figure 4.

The literature search was conducted in Scopus and Web of Science on 10 June 2026. The initial search yielded a total of 5,508 records (Scopus: 3,541; Web of Science: 1,967). Among these, 1,885 records were identified as duplicates present in both databases and were therefore removed, leaving 3,623 unique records. At this stage, 3,470 records were excluded due to lack of relevance to the topic and abstract. The remaining 153 records were then subjected to full-text assessment, during which 82 articles were excluded mainly due to not being primarily focused on the intersection of blockchain technology and supply chain resilience, or due to insufficient conceptual or empirical contribution to the research questions. Finally, 71 studies met all inclusion criteria and were retained for the systematic literature review. Only peer-reviewed publications from reputable databases were included. Study screening, full-text

assessment, quality assessment, and data extraction were conducted by a single reviewer (the first author) using the predefined inclusion and exclusion criteria and the quality assessment checklist described in this section.

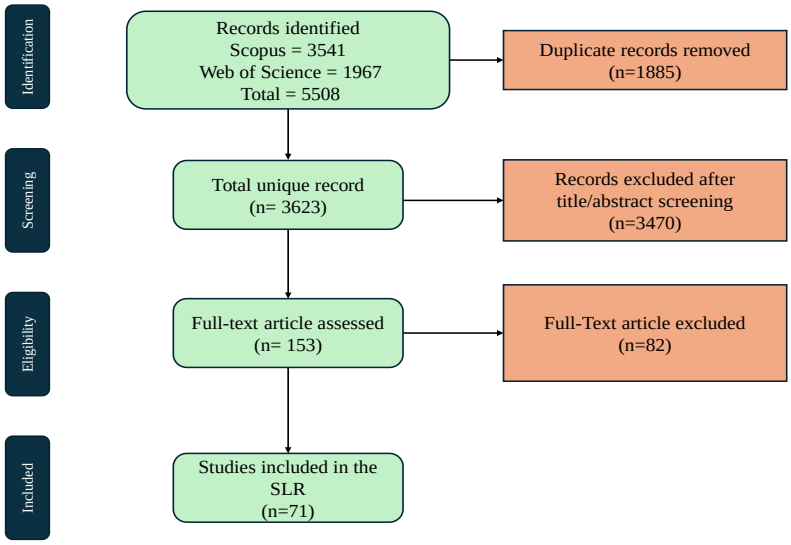


Figure 4. Diagram of study selection process (Author's own work)

4.1.1 Quality Assessment of Included Studies

To assess the methodological quality of the 71 included studies, a Quality Assessment (QA) checklist was developed based on the four quality dimensions proposed by Zhou et al. (2015): Reporting, Rigor, Credibility, and Relevance, following the approach outlined in Carrera-Rivera et al. (2022). Each study was evaluated against five criteria: (1) clarity of research aims/objectives, (2) clarity of the methodology employed, (3) direct relevance of findings to the intersection of blockchain technology and supply chain resilience, (4) discussion of limitations or validity threats, and (5) adequacy of evidence supporting the reported findings. Each criterion was scored on a three-point scale (Yes = 1, Partially = 0.5, No = 0), yielding a maximum score of 5 per study. Because scoring was performed by a single reviewer, each criterion and its scoring levels were defined in advance and applied uniformly across all studies to promote consistency. A cut-off score of 3.0 was applied to identify studies of insufficient quality; studies scoring below this threshold would have been excluded from the final synthesis or discussed separately with an explicit caveat regarding their lower methodological rigor. The average QA score across the 71 studies was 4.39 out of 5 (range 3.0–5.0). Of the 71 studies, 61 (85.9%) were rated as high quality (score ≥ 4) and 10 (14.1%) as medium quality (score from 3.0 to below 4); no study fell below the cut-off. The absence of low-quality studies likely reflects the fact that the inclusion criteria (peer-reviewed status, direct topical relevance) had already filtered out weaker sources at the screening stage. All studies were therefore retained and treated with equal weight in the descriptive synthesis, as the review's purpose was to map the breadth of the field rather than to aggregate quantitative effect sizes.

4.2 Step Two: Descriptive Analysis

In an SLR, it is valuable to analyze publications by publication year. In fact, it is quite important in an SLR to study publications by their publication date. This study allows for the identification of trends in the number of articles published over the years and in changes in research themes and focus areas. For example, looking at the number of published articles helps understand the growth in research activity. Decline and shed light on popular topics during different periods—such an examination aids in grasping trends, spotting developments, and shaping future research paths. Thus, analyzing publications by publication year is essential to conducting an SLR, enriching the research process and its ultimate discoveries.

As illustrated in Figure 5, the number of publications has shown a clear upward trend, particularly after 2020. This growth coincides with the global disruptions caused by the COVID-19 pandemic, reflecting increasing academic and practical interest in technologies that can enhance supply chain resilience. The sharp rise in publications between 2022 and 2024 suggests that blockchain is no longer viewed merely as a disruptive technology but as a potential solution for resilience in volatile environments.

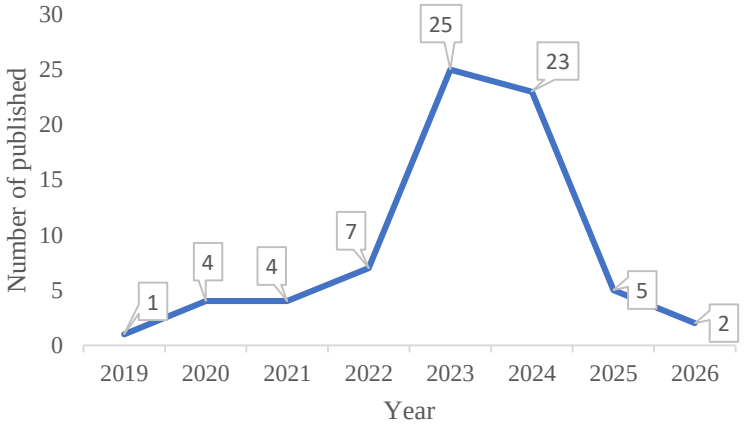


Figure 5. Trends of published documents (Author's own work)

Figure 6, created with VOS viewer, shows the co-occurrence network of author and index keywords across the included studies. Terms such as “blockchain technology,” “supply chain resilience,” and “resilience” occupy central positions, and they are linked to related terms such as “cybersecurity,” “digitalization,” and “risk management.” The clusters indicate that the literature combines technical themes (e.g., security and data management) with managerial themes (e.g., risk management and supply chain performance). As the search strategy itself contained the terms blockchain, supply chain, and resilience, their centrality is expected and mainly confirms topical coverage, whereas the secondary clusters are more informative about the thematic structure of the field.

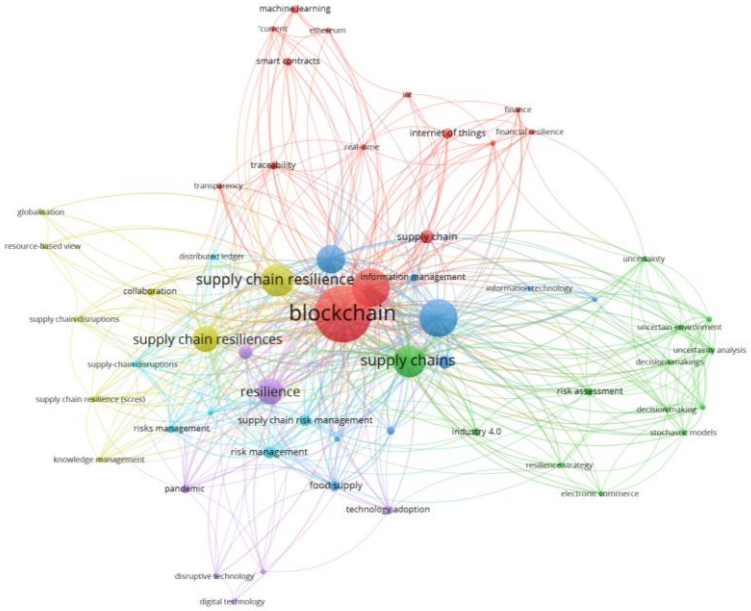


Figure 6. Keyword co-occurrence network (Author's own work)

Figure 7 shows the distribution of articles by journal or book series. The studies are widely dispersed: 42 outlets contributed a single study each (42 of 71 studies). The most frequent outlet is Computers & Industrial Engineering (n = 4), followed by Benchmarking: An International Journal, Frontiers of Engineering Management, and International Journal of Production Economics (n = 3 each). Annals of Operations Research, Business Strategy and the Environment, IEEE Transactions on Engineering Management, International Journal of Production Research, Sustainability, Transportation Research Part E, Uncertain Supply Chain Management, and Blockchain Driven Supply Chain Management each contributed two studies. This distribution indicates that research on blockchain for supply chain resilience is published mainly in operations management, industrial engineering, and sustainability outlets rather than in purely technical computer science venues, and that the field is still fragmented across many journals.

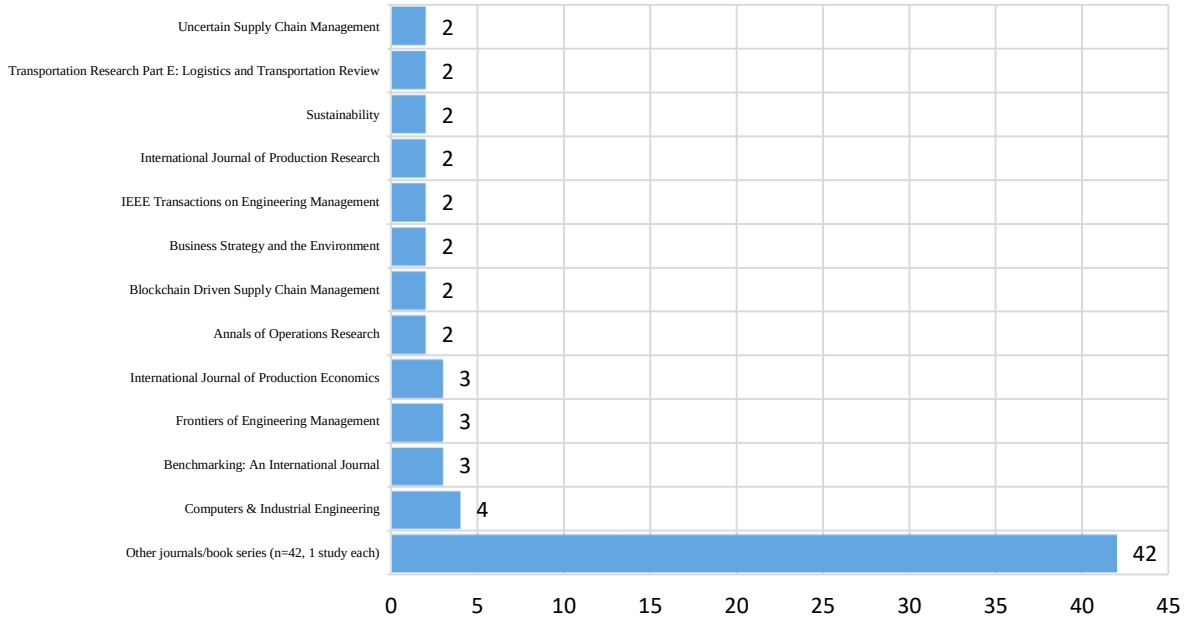


Figure 7. The distribution of articles published by journals (Author's own work)

Figure 8 shows the distribution of the top 5 cited papers published in the field of research. As can be seen, "Blockchain Technology for enhancing supply chain resilience" by (Min, 2019), "Blockchain technology for Enhancing swift-trust, collaboration and Resilience within a humanitarian supply chain setting" by (Dubey et al., 2020), "Analysis of resilience strategies and ripple effect in blockchain-coordinated supply chains: An agent-based simulation study" by (Lohmer et al., 2020), "Blockchain-supported business model design, supply chain resilience, and firm performance" by (Li et al., 2022), and "Managing disruptions and risks amidst COVID-19 outbreaks: role of blockchain technology in developing resilient food supply chains" by (Sharma et al., 2022) have the highest number of citations. The top-cited papers predominantly emphasize the role of blockchain during disruptions. This reinforces the dominance of basic blockchain features in the current literature and highlights the need for deeper investigation into advanced applications.

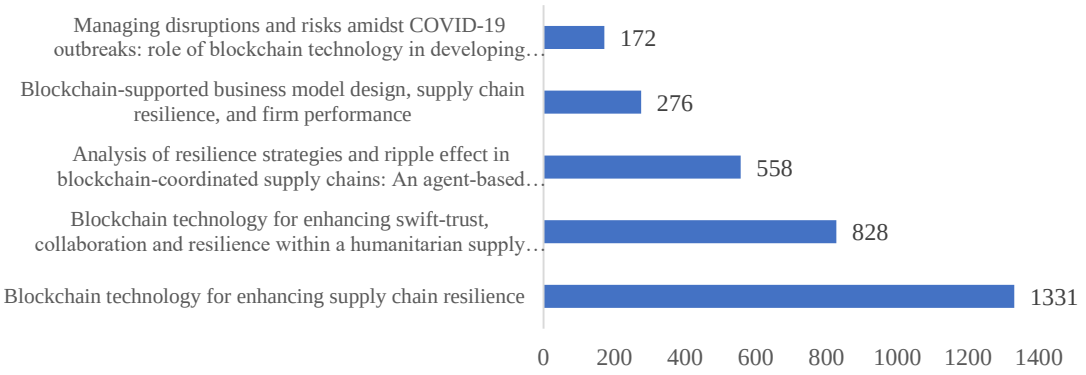


Figure 8. The distribution of the Top 5 cited papers (Author's own work)

The co-citation analysis (Figure 9) shows a highly interconnected research field. Min (2019) emerges as the most central and influential author, acting as a bridge between different research streams. This structure indicates that while the literature is growing and interdisciplinary, it is still heavily influenced by a few foundational works.

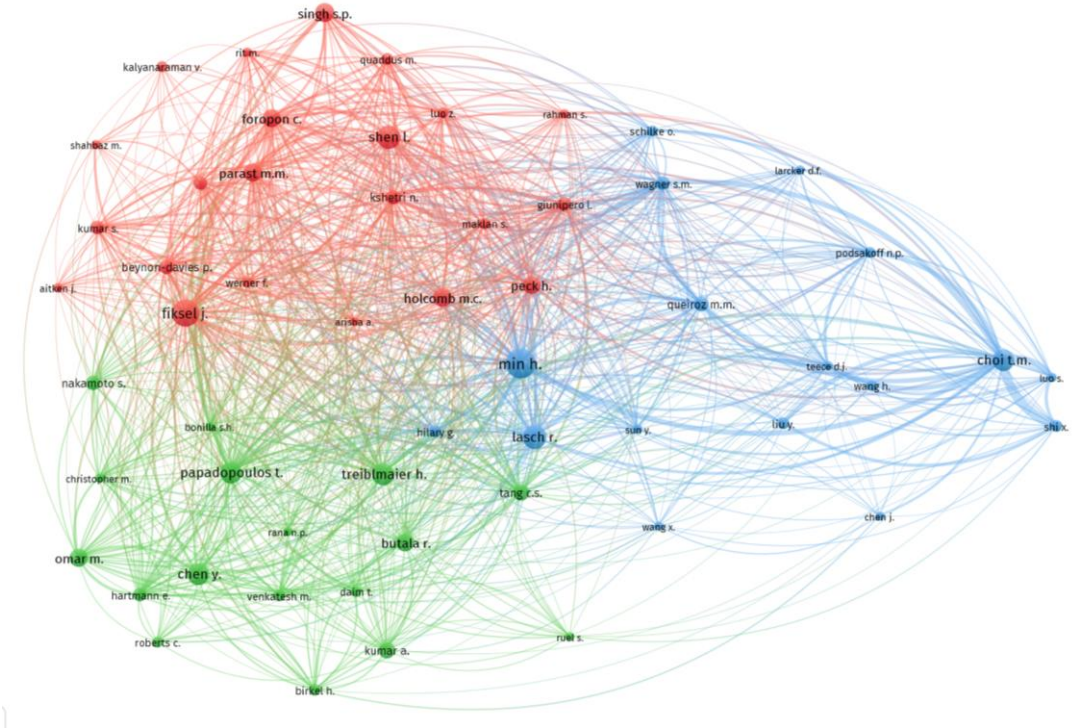


Figure 9. co-citation analysis (Author's own work)

4.3 Step Three: Content Analysis

4.3.1 Major Theme

This segment explains the study's technical aspects and illustrates the results obtained from executing the SLR protocol. The evaluation focuses on three main themes: critical success factors (CSFs), barriers, and strategies in the contexts of blockchain and resilient supply chains. Each theme is explained thoroughly with appropriate references to enhance understanding and justify the discussion.

Critical Success Factors

Analysis of the reviewed articles shows that successful adoption of blockchain in resilient supply chains relies on several interrelated Critical Success Factors (CSFs). Table 3 and Figure 10 report, for each CSF, the number of articles in which it was identified. Trust is the most frequently cited CSF, followed by Smart contracts. Traceability and Invoicing follow, then Transparency, Standardized data management, Integration of strategic partners, and Smart ordering. Security, Internal integration, and Efficient financial transactions were each identified in 9 articles, while the remaining factors appeared in eight or fewer articles. Conceptually, these factors are closely related: transparency and traceability can strengthen trust among supply chain partners, while smart contracts automate execution, reduce disputes, and accelerate transactions. This interpretation is drawn from the reviewed literature rather than from the frequency counts alone. Taken together, the findings suggest that combining visibility, trust, and automation is likely to be more effective than addressing individual factors in isolation.

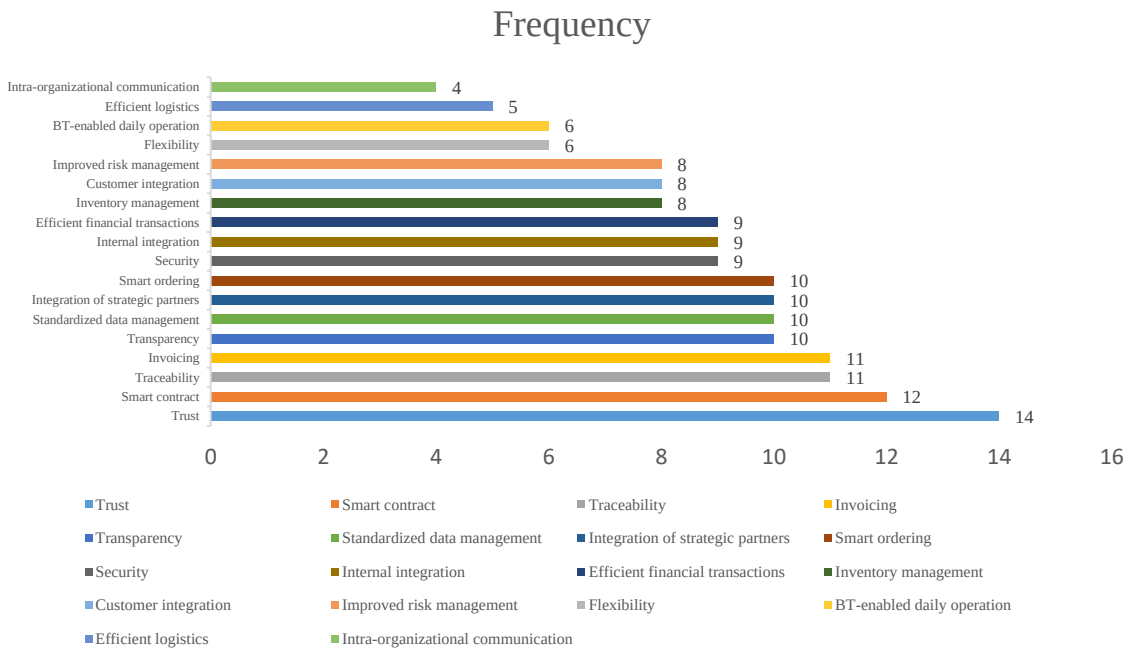


Figure 10. Frequency of critical success factors (CSFs) for blockchain adoption in resilient supply chains (Author's own work)

Table 3. CSF of implementing blockchain in the Resilient Supply Chain

CSF	Definition	Reference
Security	Using encryption alongside verification from multiple providers enhances the security of blockchain-based supply chains. These preventive measures are effective against risks such as cyberattacks or illegal entry, thereby maintaining the integrity of the supply chain.	(Akram et al., 2024; Gupta & Yadav, 2021; Kudrenko, 2024; Lohmer et al., 2020; Min, 2019; Pandey et al., 2024; Pattanayak et al., 2023; Pu et al., 2024; Yadav & Singh, 2024)

CSF	Definition	Reference
Smart contract	By removing intermediaries, smart contracts automate safe, efficient tasks with predefined instructions. For example, in resilient supply chains, smart contracts can release payments upon successful quality checks, automatically reducing disputes and delays.	(Azmi et al., 2022; Haddar & Bouaziz, 2026; Li et al., 2024; Meafa et al., 2024; Mehboob et al., 2024; Min, 2019; Nagariya et al., 2024; Nikzadipanah et al., 2024; Pandey et al., 2024; Pu & Qiao, 2024; Shahzad et al., 2025; Sim et al., 2022)
Transparency	Stakeholders are empowered to access primary information on the genesis, certifications, and other conditions products undergo, ensuring visibility. This promotes reliability amongst stakeholders and strengthens informed decision-making.	(Babaei et al., 2024; Dubey et al., 2020; Golan et al., 2020; Hu et al., 2024; Liu et al., 2024; Min, 2019; Petratos & Faccia, 2023; Shahzad et al., 2025; Singh et al., 2023; Wang et al., 2025)
Traceability	Blockchain's ability to capture every lifecycle event of a product, including manufacturing and transit, as well as updates, distinguishes it from conventional tracking. This enhances the quality assurance and thus, the resilience of the supply chain by providing accurate real-time data. For instance, tracking the handling conditions of pharmaceuticals helps in compliance and prevents spoilage.	(Dubey et al., 2020; Gupta et al., 2023; Javadpour et al., 2023; Lai et al., 2021; Li et al., 2022; Manzoor, Sahay, & Singh, 2024; Meafa et al., 2026; Niu et al., 2022; Samad & Qamar, 2023; Sim et al., 2022; Zhao et al., 2023)
Inventory management	Inventory management improves with blockchain technology because stock levels are visible in real time and procurement processes are automated. A corporation may monitor its dwindling stock using blockchain and place timely orders to avert system halts that disrupt production.	(Ali et al., 2023; Enayati et al., 2024; Gupta & Yadav, 2021; Hrušovský et al., 2022; Shi et al., 2023; Shukla & Shyam, 2023; Vivaldini & de Sousa, 2021; Yang & Yin, 2023)
Flexibility	The inherent versatility of blockchain technology is evident in how it enables sophisticated, real-time, decentralized data sharing. This allows for easier adaptation of supply chains to any form of disruption. Let's say one of the suppliers suddenly goes out of business. Blockchain enables rapid shifts to other suppliers, as resources can be redirected transparently and quickly.	(Al-Swidi et al., 2024; Dubey et al., 2020; Mishra et al., 2022; Roozkhosh et al., 2023; Sengupta et al., 2022; Zhou et al., 2025)
Internal integration	Sensors and digital tags are integrated into the blockchain, creating a single, unified interface. This improves operational efficiency as internal processes are automated. A good example is that logistics departments can use automated updates from the blockchain to determine when a shipment has been completed.	(Al-Swidi et al., 2024; Datta et al., 2023; Dutta et al., 2020; Enayati et al., 2024; Gajek et al., 2021; Li et al., 2022; Min, 2019; Sengupta et al., 2022; Shahzad et al., 2025)
Standardized data management	Standardization and the creation of unmodifiable records help prevent data falsification and uphold accountability. This can be achieved by implementing blockchain in food supply chains to enhance confidence and compliance by verifying food temperature during transportation.	(Ababneh et al., 2023; Abadi et al., 2024; Beck et al., 2023; Dubey et al., 2020; El Ouarrak & Hmioui, 2024; Li et al., 2022; Lohmer et al., 2020; Min, 2019; Nagariya et al., 2024; Nozari et al., 2024)
Trust	Evidence that blockchain enables trust between organizations is the existence of transparent, immutable records. This trust facilitates partnering because stakeholders can rely on the blockchain's trustless nature to execute agreements and monitor transactions.	(Abadi et al., 2024; Azmi et al., 2022; Beck et al., 2023; Chen et al., 2023; Dutta et al., 2020; El Haddouti et al., 2024; El Ouarrak & Hmioui, 2024; Golan et al., 2020; Margret et al., 2024; Min, 2019; Nozari et al., 2024; Nozari et al., 2025; Pal, 2023; Wang et al., 2025)

CSF	Definition	Reference
Efficient logistics	Blockchain reduces logistics costs by automating compliance and document management. For example, the delivery of goods is not delayed because customs clearance using blockchain-authenticated certificates is expedited.	(Gupta & Yadav, 2021; Kazancoglu et al., 2023; Li et al., 2022; Min, 2019; Pandey et al., 2024)
BT-enabled daily operation	Blockchain simplifies daily operations by automating repetitive tasks, such as transaction validation. This efficiency reduces costs and frees up resources for strategic planning. For example, companies can use blockchain to reconcile invoices, improving cash flow automatically.	(Dutta et al., 2020; Min, 2019; Mohamed et al., 2023; Pandey et al., 2024; Pattanayak et al., 2023; Sim et al., 2022)
Invoicing	Blockchain improves invoicing processes by verifying transactions in real-time and eliminating unnecessary delays. For instance, blockchain enables suppliers to receive payments promptly upon delivery confirmation.	(Akram et al., 2024; Alabaddi et al., 2023; Li et al., 2022; Min, 2019; Mubarik et al., 2023; Pandey et al., 2024; Pattanayak et al., 2023; Petratos & Faccia, 2023; Samad & Qamar, 2023; Shukla & Shyam, 2023; Wang & Bai, 2023)
Intra-organizational communication	Blockchain improves communication by securely transferring information across organizational units. This contributes to operational cohesion within businesses, as aligned functions improve supply chain resilience.	(Dou et al., 2025; Hu et al., 2024; Pandey et al., 2024; Wang & Bai, 2023)
Integration of strategic partners	Strategic partners can work together more effectively because blockchain enables transparent information sharing. This allows suppliers and manufacturers to exchange production schedules on the blockchain, facilitating lower lead times and greater responsiveness.	(Akhavan & Philsoophian, 2023; Dubey et al., 2020; Gupta & Yadav, 2021; Min, 2019; Pal, 2023; Pandey et al., 2024; Pattanayak et al., 2023; Roozkhosh et al., 2023; Vivaldini & de Sousa, 2021; Wang & Bai, 2023)
Customer integration	Integration of customers using blockchain is made easier by providing up-to-date information on product delivery and certification. For instance, customers can track their orders and remotely certify them, thereby fostering credibility and loyalty.	(Hrušovský et al., 2022; Lau et al., 2023; Manzoor, Sahay, & Singh, 2024; Mishra et al., 2022; Nikzadipanah et al., 2024; Pandey et al., 2024; Pu & Qiao, 2024; Shi et al., 2023)
Efficient financial transactions	Financial calculations are made more efficient by reducing intermediaries and delays through smart contracts on the blockchain. An example is the quick, secure execution of cross-border transactions, which ensures operational continuity.	(Akram et al., 2024; Li et al., 2022; Min, 2019; Pandey et al., 2024; Pattanayak et al., 2023; Petratos & Faccia, 2023; Samad & Qamar, 2023; Shukla & Shyam, 2023; Wang & Bai, 2023)
Improved risk management	Blockchain also makes it easier to manage visibility of issues by providing real-time insight into risk levels and potential impacts on supply chains, enabling effective, proactive risk management. Being able to monitor disruptions in the supply chain empowers companies to respond in real time, helping them preserve their resilience.	(Alabaddi et al., 2023; Beck et al., 2023; Dubey et al., 2020; Dutta et al., 2020; Golan et al., 2020; Hrušovský et al., 2022; Lau et al., 2023; Pandey et al., 2024)
Smart ordering	Blockchain improves ordering systems by tracking and validating critical data like pricing, delivery schedules, and certifications. For example, companies can ensure compliance with sustainability standards by verifying supplier data on the blockchain.	(El Ouarrak & Hmioui, 2024; Hu et al., 2024; Li et al., 2024; Manzoor, Sahay, & Singh, 2024; Margret et al., 2024; Meafa et al., 2024; Min, 2019; Nikzadipanah et al., 2024; Nozari et al., 2024; Pandey et al., 2024)

Challenges

Analysis of the 71 reviewed articles shows that, despite its potential, several significant challenges hinder the widespread adoption of blockchain technology in resilient supply chains. As presented in Table 4 and Figure 11, Scalability is the most frequently cited challenge, appearing in 9 articles. Complexity and Lack of acceptance in the industry follow, each in 7 articles. Cost and resource constraints and Government support are each cited in 6 articles, followed by Labor management, Organizational resistance, and Lack of expertise, and finally Market uncertainty. The distribution suggests that technical challenges (especially Scalability and Complexity) feature most prominently in the literature. Overall, these multifaceted challenges indicate that successful blockchain implementation requires simultaneous attention to technical, organizational, and regulatory issues.

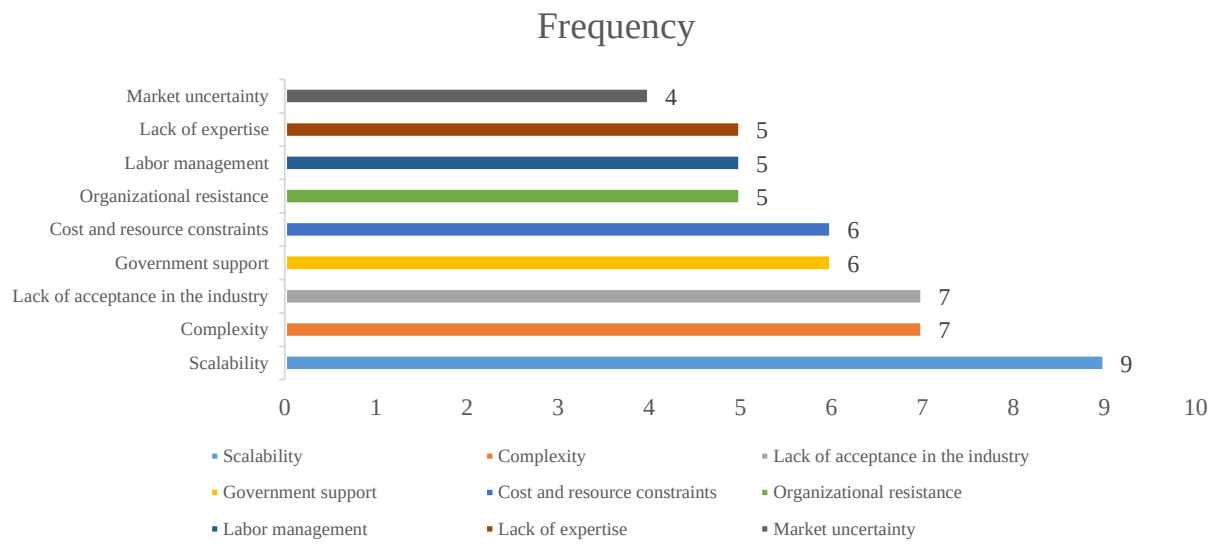


Figure 11. Frequency of main challenges in adopting blockchain for resilient supply chains (Author's own work)

Table 4. Challenges of implementing blockchain technology in the resilient supply chain

Challenge	Definition	References
Cost and resource constraints	The integration of blockchain technology into supply chains may be constrained by its costs and resource requirements. Moreover, highly specialized infrastructure expenditures, specialized knowledge gaps, and the excessive time required to implement new systems may also retard progress.	(Akram et al., 2024; Al-Swidi et al., 2024; Beck et al., 2023; Datta et al., 2023; Dutta et al., 2020; Lai et al., 2021)
Complexity	In complex supply environments, coordinating between multiple stakeholders and integrating blockchain with existing systems can be difficult. These complexities may hinder blockchain's ability to enhance resilience.	(Akram et al., 2024; Chen et al., 2023; Manzoor, Sahay, & Singh, 2024; Min, 2019; Roozkhosh et al., 2023; Shukla & Shyam, 2023; Singh et al., 2023)
Scalability	Scalability challenges can limit the use of blockchain in supply chains. Especially in supply chains with numerous stakeholders and large volumes of data, scalable technologies are essential for processing data quickly and securely.	(Akram et al., 2024; Dutta et al., 2020; Min, 2019; Mubarik et al., 2023; Nagariya et al., 2024; Nikzadipanah et al., 2024; Roozkhosh et al., 2023; Shahzad et al., 2025; Shi et al., 2023)
Labor management	The challenge posed by personnel trained to install and maintain blockchain systems is paramount in the system's setup. In the absence of an appropriate workforce, blockchain technology cannot be used to enhance resilience.	(Pandey et al., 2024; Pattanayak et al., 2023; Shukla & Shyam, 2023; Singh et al., 2023; Wang & Bai, 2023)

Challenge	Definition	References
Government support	Another challenge is inadequate legal and governmental assistance concerning blockchain technology and supply chain resilience. This means there will be no assistance for technology implementation, increasing the regulatory burden and introducing red tape challenges.	(Al-Swidi et al., 2024; Ali et al., 2023; Datta et al., 2023; Enayati et al., 2024; Gupta & Yadav, 2021; Gupta et al., 2023)
Organizational resistance	The adoption of blockchain technology may be impeded by organizational inertia. Many organizations may be reluctant to change workflows or adopt blockchain, even when the technology would increase resilience.	(Lau et al., 2023; Li et al., 2022; Li et al., 2024; Li et al., 2023; Min, 2019)
Market uncertainty	Involves unpredictability in the demand, supply, accepted price, time of delivery, and acceptance of the product. An array of uncertainties regarding the scenario impacts stakeholders and disrupts supply chains, as seen in the shortage of essentials during the COVID pandemic. Such uncertainties can create barriers to investment, further stifling the resilience needed to adopt technologies like blockchain.	(Al-Swidi et al., 2024; Li et al., 2024; Lohmer et al., 2020; Manzoor, Sahay, & Singh, 2024)
Lack of expertise	The shortage of blockchain specialists and the technical expertise required for its implementation are the biggest barriers to adoption. The most noteworthy impediment to adopting technology is the lack of professionals trained in blockchain and the skilled labor needed to implement it. This workforce gap can hinder the ability to leverage blockchain to improve supply chain resilience.	(Akram et al., 2024; Al-Swidi et al., 2024; Beck et al., 2023; Datta et al., 2023; Dutta et al., 2020)
Lack of acceptance in the industry	BT has been recognized as a resilient tool for fostering a socially responsible, sustainable supply chain. Despite these advantages, there is a strong reluctance to adopt BT across many sectors. This reluctance could, in the long run, hinder the use of BT in a sustainable, socially responsible supply chain.	(Abadi et al., 2024; Dubey et al., 2020; El Ouarrak & Hmioui, 2024; Li et al., 2024; Roozkhosh et al., 2023; Samad & Qamar, 2023; Shahzad et al., 2025)

Strategies

The final part of the major theme is to assess different supply chain resilience strategies and the influence of blockchain technology on the resilience approach.

Supply Chain Reengineering: Reengineering reviews and modifies processes and structures to improve performance while minimizing waste. Blockchain contributes immutable records of resource use and disposal, which improve accountability in waste management and operational sustainability. Automated process tasks allow leaner network structures, so resources can be reallocated and configurations adjusted quickly when disruptions occur (Lohmer et al., 2020; Nagariya et al., 2024).

Supply Chain Collaboration/Connectivity: Collaboration depends on partners sharing information on inventory levels, delivery schedules, and demand, which a common ledger makes possible and thereby improves coordination (Min, 2019). Payments released automatically upon delivery confirmation reduce disputes and manual errors (Lohmer et al., 2020). Blockchain also supports network governance through role-based access control and predefined decision-making protocols, which helps align stakeholders during disruptions and speeds recovery (Beck et al., 2023; Nagariya et al., 2024). By integrating blockchain into supply chain collaboration and connectivity, organizations can create supply chains that are not only more efficient but also more resilient to uncertainties and disruptions. The enhanced reliability, visibility, and operational agility provided by blockchain ensure that modern supply chains remain robust and adaptable in an increasingly dynamic global environment (Lohmer et al., 2020; Min, 2019; Nagariya et al., 2024).

Supply Chain Agility: Agility in supply chains depends on rapid information flow and the ability to respond quickly to changes. Blockchain supports this capability by providing a shared ledger that gives stakeholders timely access to data on inventory levels, shipments, and supplier performance. This improved visibility allows organizations to detect disruptions earlier and take corrective action (Lohmer et al., 2020). In addition, smart contracts automate routine processes such as payments and inventory adjustments, which removes procedural bottlenecks and accelerates operational responses. The same infrastructure also makes it easier to onboard new partners, since trust and compliance can be established through secure data sharing without lengthy manual verification (Nagariya et al., 2024).

Supply Chain Risk Management: Risk management requires an integrated view of threats and disruptions. Greater visibility and communication along the value chain enable faster identification of problems and execution of contingency plans, and transparent supplier profiles with verified compliance records improve risk awareness and reduce the likelihood of disruption (Min, 2019). Permanent, tamper-proof records also strengthen knowledge management by providing a reliable basis for developing response strategies (Lohmer et al., 2020; Min, 2019; Nagariya et al., 2024).

Supply Chain Capability: Supply chain capability includes information sharing, coordination, integration, and collaboration. Blockchain strengthens these elements by creating a secure and distributed system for data exchange, which reduces errors and supports more consistent decision-making across partners. Smart contracts further contribute by automating processes related to payments, costs, and inventory control. By aligning operations on a shared ledger, blockchain also facilitates closer integration among supply chain partners and improves overall coordination (Lohmer et al., 2020; Nagariya et al., 2024).

Supply Chain Innovation: Supply chain innovation involves optimizing business processes and leveraging technology to improve responsiveness and value creation. Blockchain supports process innovation by providing an accurate and accountable ledger that improves the management of stock movements, supplier validation, and automated workflows through smart contracts (Beck et al., 2023). When combined with artificial intelligence, blockchain further enables predictive analytics and faster responses to market changes. In addition, it facilitates cooperation within vertical and horizontal logistics networks by allowing partners to share information and resources in a distributed manner without relying on a central authority (Lohmer et al., 2020; Nagariya et al., 2024).

Supply Chain Performance Outcome: Supply chain performance outcomes are multidimensional and can be improved through the targeted use of blockchain technology. One key benefit is cost reduction, achieved by eliminating inefficiencies in transactional processes and reducing administrative overhead and data inaccuracies (Min, 2019). Blockchain also supports quality improvement by enabling accurate tracking of materials and products throughout the supply chain. This visibility helps minimize defects and allows customers to verify product origin and production information, which strengthens trust and loyalty (Manzoor, Sahay, & Singh, 2024). In addition, the automation of processes through smart contracts shortens lead times and accelerates supplier interactions. Finally, the availability of reliable records on inventory levels and resource allocation improves planning and coordination, reducing the risks of overstocking or stockouts and enhancing overall operational efficiency (Lohmer et al., 2020; Nagariya et al., 2024).

Supply Chain Flexibility: Flexibility at multiple levels is essential for maintaining supply chain adaptability. Blockchain supports supplier selection by enabling more transparent data sharing, which facilitates evaluation processes and the development of stronger supplier relationships (Manzoor, Sahay, Gumte, et al., 2024). Process and production flexibility are improved through better tracking and coordination of activities, allowing organizations to respond to changing market demands while maintaining efficiency and quality. In distribution and transportation, improved visibility helps ensure on-time delivery and reduces logistical risks. Finally, smart contracts and shared data records enhance order fulfillment flexibility by supporting more responsive and customizable fulfillment processes (Lohmer et al., 2020; Nagariya et al., 2024).

4.3.2 Discussion and Future Directions

The next step is to examine the research gap according to question two. This section discusses the analysis and evaluation of the technical aspects of the SLR presented in the previous section and provides future research directions.

Gap in Technology

The technological gap analysis in Figure 12 required the full-text review of all 71 articles. For each article, the dominant technological characteristics were used to determine the generation of blockchain the research was primarily focused on and classified as such. The classifications of Blockchain 1.0, 2.0, 3.0, 4.0, and 5.0 were manually assigned, and the frequencies of each were used to construct the figure. The results express technological inequity in the research of

blockchain-enabled supply chain resilience. Approximately 35% (n = 25) of the reviewed articles addressed Blockchain 1.0, 30% (n = 21) focused on Blockchain 2.0, 25% (n = 18) on Blockchain 3.0, while only 7% (n = 5) and 3% (n = 2) examined Blockchain 4.0 and 5.0, respectively.

This distribution reflects a structural limitation rather than a simple preference. Blockchain 1.0 through 3.0 are fundamentally transactional: they record and verify what has already occurred (a shipment confirmed, a payment released, a record shared across nodes) rather than anticipating what is about to happen. Since these three generations together account for 90% of the reviewed literature, the field has predominantly approached blockchain as a tool for securing and verifying past and present states of the supply chain, which by design can only support a reactive resilience posture. Predictive and adaptive capabilities, by contrast, depend on the intelligent-infrastructure layer of Blockchain 4.0/5.0, where integration with AI and IoT enables systems to sense anomalies and reconfigure operations before disruptions reach full impact; the near-absence of research at this level (only 10% combined) means organizations adopting blockchain today largely gain transparency and traceability, but not early-warning or autonomous response capabilities.

This asymmetry is reinforced by the absence of studies in the reviewed corpus on blockchain oracles, cross-chain interoperability, Zero-Knowledge Proofs (ZKP), or Secure Multi-Party Computation (SMC). These are precisely the technologies capable of feeding real-time external data into smart contracts (oracles), enabling secure interoperability across siloed networks (cross-chain), and allowing sensitive data to be verified or jointly processed without disclosure (ZKP, SMC) — all prerequisites for moving from a reactive to a proactive resilience model. Their absence suggests the conceptual link between advanced blockchain capability and predictive resilience remains largely unestablished, leaving current frameworks confined to a defensive function (protecting transaction integrity) rather than an anticipatory one (foreseeing and adapting to disruptions before they materialize).

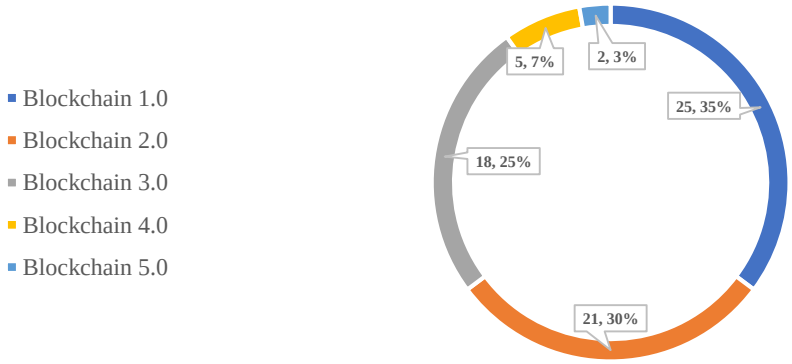


Figure 12. Distribution of blockchain technologies used in SCRES (Author's own work)

This distribution highlights a research gap in advanced, specialized blockchain technologies, underscoring their inclusion in the subsequent subsections as critical areas for future exploration to enhance supply chain resilience.

Oracle: A blockchain oracle is a decentralized information network (often called an oracle) that enables real-world information to be entered into and retrieved from blockchains. Oracles function as specialized intermediaries relaying pertinent data to smart contracts, enabling their execution based on current conditions. These oracles enable smart contracts to integrate off-chain data and functionalities into their on-chain processes, thereby expanding their practicality and scope (Caldarelli, 2022). Blockchain oracles not only provide contracts with real-world information but can also predict market and supply chain risks. Advanced analytics, along with real-time data, enable faster, more precise decision-making. For example, Al-Breiki et al. (2020) argue that oracles can provide significant information relevant to the supply chain, such as weather conditions, market prices, and global transportation logistics. Key

characteristics of a resilient supply chain include sufficient backup inventory, regional diversification of suppliers, advanced digital systems for data visibility and monitoring, proactive protective measures, equitable franchise proliferation, and fairness in distribution (Shen et al., 2023).

Oracles can facilitate supply chain activities by adapting more precisely in real life through blockchain registers. Oracles act as trusted third-party services that provide external information to smart contracts, enabling the supply chain to respond more effectively to inventory fluctuations, price changes, and geographic and environmental conditions. This aid can enhance the supply chain's risk resilience while maintaining equilibrium between inventory and demand. In addition to these new possibilities, blockchain oracles could also improve supply chain predictability and, consequently, decision-making. This is in part due to the availability of important real-time information, such as weather, market prices, and transport status, which is crucial for the proper functioning of supply chains. This proactive response to information helps mitigate delays, inventory shortages, and additional expenses in a timely and effective manner.

Furthermore, integrating oracles with artificial intelligence systems enables more sophisticated data analysis, the detection of risk patterns, and the provision of the best response in emergencies. These technologies are extremely important in the face of global disruptors, such as pandemics or unanticipated demand shifts, ensuring that supply chains continue to function smoothly while providing economic and operational stability. In this manner, oracles act as connectors between the real world and data and information systems based on blockchain technology. More importantly, they help build responsive, almost autonomous systems to address endless, unforeseen changes and complex risks.

Cross-Chain: Cross-chain technology facilitates interoperability between different blockchain systems (Jiang et al., 2019). It addresses the challenge of information barriers by enabling the exchange of data and assets across various blockchains. The security concerns in cross-chain applications include authentication, consensus transmission, and protection against quantum computing attacks. A quantum cross-chain model (QCC) has been proposed to enhance security, incorporating access control policies, authentication methods, and a quantum ring signature scheme for secure transactions. Cross-chain technology enables communication between different blockchain networks, which is a very critical challenge. It is considered a fundamental development that fosters the connection of various blockchains. It uses customizable protocols, enabling users to transmit information and assets securely, without the need for centralized third parties (Ou et al., 2022). One of the most critical features of cross-chain technology is enabling trusted inter-chain interactions, which can facilitate complex transactions, such as asset swaps between public and private chains or the execution of hybrid smart contracts. Other challenges include ensuring data integrity and aligning consensus protocols across different blockchains, which are being addressed through advancements such as trusted communication channels and multi-chain bridges (Jiang et al., 2019). Cross-chain technology also enhances access to the diverse resources of various blockchains. This capability allows developers to leverage the strengths of multiple chains, such as the security of private blockchains and the scalability of public ones, in a unified ecosystem (Datta et al., 2024).

The dual application of cross-chain technology and the quantum model QCC can significantly increase the security and flexibility of the supply chain. Cross-chain technology enhances collaboration among parties by enabling data transfer between blockchains, enabling faster responses to unexpected issues. This enables fast responses to unforeseen difficulties. On the other hand, QCC uses modern verification and security methods to protect transactions, increasing transparency and fairness in the supply chain. Moreover, cross-chain technology not only expands the capability for data and asset transfer across multiple blockchains but also improves the efficiency of the supply chain. It enables the creation of multi-chain smart contracts that can automate complex tasks, such as coordinating multiple suppliers or managing the distribution of goods.

On the other hand, the quantum cross-chain model not only improves security but also scalability. This model employs quantum-resistant cryptographic protocols to safeguard sensitive data, such as customer details and transactional information, providing a higher degree of protection. Moreover, QCC’s quantum ring signature ensures

the secrecy and anonymity of transactions. Cross-chain technology also enhances access to the diverse resources of various blockchains. Meaning that relevant data can be accessed securely by suppliers and customers without privacy being compromised. Such capabilities can improve decision-making, reduce process step latency, and strengthen the supply chain.

Zero-Knowledge Proof (ZKP): Zero-knowledge-proof blockchain integrates zero-knowledge proofs with blockchain systems to improve security, privacy, and efficiency across various applications. Zero-knowledge proofs enable verification of data without disclosing the information, ensuring confidentiality (Sun et al., 2021) . Through ZKP, supply chain actors can verify important details without disclosing sensitive data, thereby improving security and privacy. For example, ZKP can validate confidential information, secure product authentication, and verify transactions across digital ledgers without disclosing sensitive information. This can mitigate the risk of data breaches or fraud, promoting reliability among participants.

Moreover, ZKP can improve the efficiency of supply chain operations by streamlining verification processes and reducing the need for manual intervention, ultimately fostering transparency and ensuring a fair distribution of resources. Therefore, integrating ZKP into the supply chain aligns with the characteristics of resilience, such as proactive protective measures and the use of advanced digital systems, leading to a more robust and adaptable supply chain ecosystem. ZKP technology directly enhances supply chain resilience. ZKP helps to limit the amount of sensitive information that can be disclosed within a group of suppliers, customers, and other relevant parties. This attribute is essential for a resilient supply chain, as it protects against cyber warfare and data exposure. ZKP enables quick, secure verification of information, allowing the supply chain to respond more effectively to crises such as sudden demand fluctuations or logistical disruptions. Using ZKP, supply chain partners can verify critical information without sharing sensitive details. This strengthens credibility and fosters better coordination among stakeholders. ZKP ensures that goods and processes comply with specified standards without revealing behind-the-scenes details.

Secure Multi-Party Computation (SMC): SMC is an advanced branch of cryptography that enables multiple independent entities to execute computations on their own private inputs without revealing any of those inputs to each other. Specialized protocols guarantee confidentiality, ensuring that each participant produces an accurate, agreed-upon output. The primary concern for SMC is ensuring data privacy and security during joint computation, which makes it a relevant technology in sensitive areas such as data analytics, banking, healthcare, and cloud computing. SMC addresses privacy concerns in trustless environments by providing a secure framework for distributed interactions (Zhao et al., 2019). Secure multi-party computation enhances the security of supply chains by enabling interested parties to compute outcomes while keeping their proprietary information confidential. This approach enables participation in activities such as refined demand planning, inventory assessment, and supplier evaluation while safeguarding data access without compromising data privacy. SMC mitigates data breach risks and cultivates trust among parties by ensuring data confidentiality and integrity, which is vital for disruption management. Moreover, SMC promotes greater cooperation among participants in global, decentralized supply chains, ensuring responsive risk adaptation without sacrificing competitive advantage. SMC enables stakeholders to expose sensitive data that would otherwise be confidential, making SMC invaluable to the resilience of supply chains. This capability allows companies to exchange critical data, such as production capacities, logistical constraints, or financial metrics, while maintaining data privacy and confidentiality. SMC also enhances collaborative decision-making. For instance, in supply chains involving multiple suppliers, SMC protocols enable joint optimization in resource allocation or delivery scheduling. This process not only mitigates risks associated with a lack of transparency but also facilitates better coordination and quicker responses to sudden changes. Moreover, by reducing the need for complete trust among partners, SMC can support the onboarding of new suppliers and the expansion of supply chain networks. This technology, through its robust data security and trust-building mechanisms, strengthens the supply chain's ability to address challenges such as demand fluctuations, logistical disruptions, and cybersecurity threats.

Concept

This section discusses gaps in the literature regarding the application of blockchain technology to resilient supply chains. Despite the rich literature available, some factors remain underexplored. Focusing on these factors can optimize the efficacy and efficiency of blockchain technology in enhancing supply chain resilience. This research aims to address gaps in improving the responsiveness, adaptability, and sustainability of supply chains through blockchain technology, benefiting scholars and industry experts.

- Based on Table 3 (CSF of blockchain) and Figure 1 (depicting the 8 stages of resilience), a decision-making framework can be established. This framework enables organizations and stakeholders to determine which critical success factors are most suitable for each stage of resilience, thereby maximizing efficiency and impact. The importance of this angle lies in improving not only the efficiency of operations but also the strategic deployment of blockchain solutions in a difficult, crisis-prone industry;
- Regular evaluations support ongoing monitoring and improvement of system performance. These evaluations reveal gaps, strengths, and potential areas for improvement. One of the best tools for these evaluations is the application of maturity models. These models enable performance evaluation over time by identifying strengths and weaknesses, setting strategic goals, and providing detailed steps to achieve them. In addition, maturity models allow an organization to assess its current state relative to industry standards and best practices, helping identify performance gaps and formulate focused strategies to eliminate them. This, in turn, improves organizational efficiency, adaptability, performance, and strategic focus. These models also enable organizations to respond to environmental changes, technological complexities, and managerial issues;
- Furthermore, maturity models provide means for periodic strategy revision and progress tracking to ensure alignment with organizational objectives. This iterative approach ensures that organizations are on course toward their long-term objectives. Ultimately, adopting maturity models improves decision-making, reduces costs, and enhances transparency in managing systems, making them invaluable for driving sustainable growth and performance excellence;
- Each generation of blockchain technology finds its relevance in specific industries, and analyzing these applications through the lens of supply chain resilience provides a valuable perspective. By aligning the capabilities of each blockchain evolution—with financial transactions in Blockchain 1.0, smart contracts in Blockchain 2.0, global transparency in Blockchain 3.0, real-world integration in Blockchain 4.0, and intelligent systems in Blockchain 5.0—organizations can identify the most effective use cases for their unique needs. This alignment helps maximize effectiveness, reduce vulnerabilities, and maintain strong, flexible supply chain systems. This view is especially important because it integrates the technological breakthroughs of blockchain with the operational needs of a resilient supply chain system. Each generation of blockchain offers new functionalities, such as decentralized trust systems and automated reasoning, that address specific problems in supply chain management, including transparency, traceability, risk reduction, and efficiency. Knowing how each phase of blockchain interacts with the logic of resilience enables evaluating, in a stepwise manner, the potential mitigation of disruptions, cyberattacks, natural disasters, and even economic downturns. For instance, Blockchain 1.0's secure digital transactions can enhance financial resilience, while Blockchain 2.0's smart contracts ensure process continuity and reduce dependency on intermediaries. Blockchain 3.0 and 4.0 offer unprecedented transparency and real-world integration, both of which are essential for building adaptive, robust supply chains. At the same time, Blockchain 5.0, with AI and IoT, incorporates preemptive and self-sufficient approaches aligned with proactive resiliency disciplines. The gap in the existing literature that remains unaddressed is the linkage between advanced blockchain technology and supply chain resilience, particularly its integration with AI and IoT. By

addressing this disconnect, theorists and practitioners will be better positioned to maximize the potential of blockchain technology beyond a simple efficiency tool to a robust multi-dimensional proposition for sustained resilience. This does more than amplify the application of blockchain; it enhances the sustainability, security, and adaptability of supply chains across different sectors;

- The use of blockchain technology to reduce the resiliency curve of supply chains and improve efficiency during critical situations remains an unaddressed issue in both blockchain and supply chains. In times of crisis, the supply chain suffers significant disruptions from cyberattacks, natural disasters, and even recessions. Blockchain technology's features, including transparency, reliability, and automation, are fundamental to improving the system's resiliency and responsiveness during these crises. Research efforts should examine how the temporal constraints imposed by critical situations can be altered by applying blockchain to improve interaction among supply chain parties, enhancing coordination and response time. Furthermore, the role of blockchain's traceability features and the removal of intermediaries must be analyzed to create transparency and improve decision-making in emergencies. Offering organizations tools to improve efficiency during crises, resilience, and to anticipate future challenges using blockchain technology highlights the need to bridge this research gap;
- Dynamic Capabilities Theory (DCT) provides a strong theoretical framework for integrating the findings of this study. The core characteristic of DCT is its emphasis on how organizations build and sustain competitive advantage in volatile and rapidly changing environments through three key processes: Sensing (identifying opportunities and threats through scanning, search, and learning), Seizing (mobilizing resources and making timely decisions to capture opportunities), and Reconfiguring (transforming, recombining, and renewing assets, processes, and structures for continuous adaptation) (Teece, 2007). These processes align closely with the concept of resilience, as both DCT and resilience focus on adaptation, learning, recovery, and transformation in the face of disruptions. Therefore, the critical success factors, challenges, and strategies identified in this study can be integrated into a single conceptual model grounded in DCT, illustrating how blockchain technology acts as a key that strengthens these dynamic capabilities to enhance supply chain resilience.

Proposed Conceptual Framework

Based on the comprehensive synthesis of the critical success factors, adoption challenges, resilience strategies, and identified technological gaps, an integrated conceptual framework is proposed (see Figure 13). This framework illustrates the pathway through which blockchain critical success factors enable adoption in supply chains, which subsequently fosters resilience strategies and leads to improved performance outcomes. Simultaneously, various challenges act as inhibitors across all stages of this process. Furthermore, emerging blockchain technologies such as oracles, cross-chain interoperability, zero-knowledge proofs, and secure multi-party computation are highlighted as key directions for future research to strengthen the framework and enhance supply chain resilience.

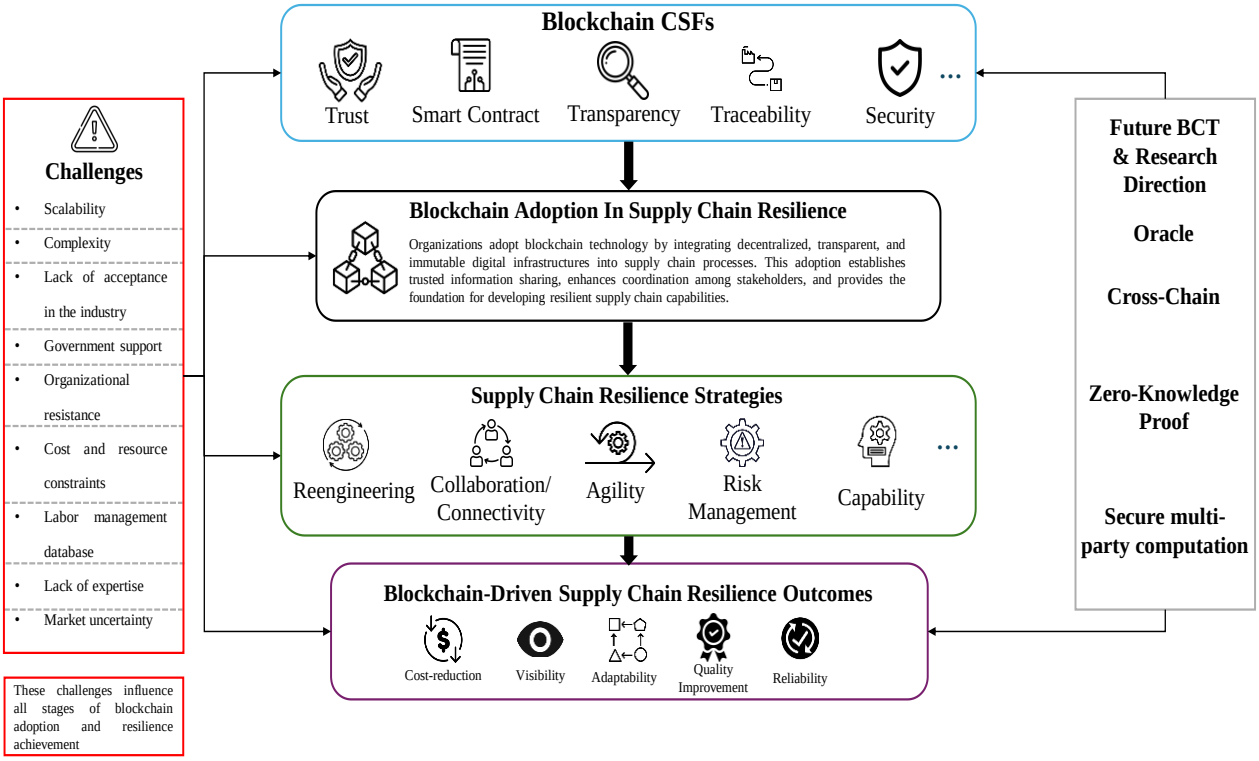


Figure 13. Conceptual framework for BCT adoption in fostering resilient supply chains (Author's own work)

5. Conclusion

In an era marked by increasing global disruptions, such as pandemics, natural disasters, cyberattacks, and economic instabilities, building resilient supply chains is critical for ensuring operational continuity and competitive advantage. Blockchain technology, with its inherent features of transparency, immutability, and decentralization, has emerged as a transformative tool to enhance supply chain resilience (SCRES). A systematic literature review examining blockchain technology, SCRES, and their relationship was conducted using 71 peer-reviewed articles published from 1 January 2019 to 10 June 2026. The necessity of this research lies in addressing the growing complexity of global supply chains and the limitations of traditional risk management approaches, which struggle to handle unpredictable disruptions. By examining blockchain's potential to foster adaptability, trust, and efficiency, this study bridges a critical gap in the literature. It provides a foundation for leveraging blockchain to create robust, sustainable supply chains.

The SLR yielded multiple findings on the role of blockchain technology in SCRES. First, among the critical success factors, trust, smart contracts, traceability, and transparency were the most frequently identified, suggesting that visibility, trust, and automation are central to how blockchain supports resilience (see Table 3). Second, despite these enabling factors, challenges such as scalability, complexity, limited industry acceptance, cost constraints, and insufficient government support hinder adoption (see Table 4). Third, resilience strategies, such as supply chain reengineering, collaboration, agility, and risk management, are strengthened by blockchain's capabilities, including smart contracts and decentralized ledgers. However, the analysis highlights a significant research gap: only about 10% of the reviewed studies addressed Blockchain 4.0 and 5.0, and none addressed advanced technologies such as oracles, cross-chain interoperability, zero-knowledge proofs, or secure multi-party computation (see Figure 12). This limits the ability to address complex resilience challenges, such as real-time adaptability and secure cross-network collaboration.

5.1 Recommendations for Future Research

To advance the field, this study proposes technological and conceptual recommendations for future research, each with practical implications for researchers and industry practitioners.

5.1.1 Technological Recommendations

1. **Adoption of Advanced Blockchain Technologies**: Researchers should focus more on Blockchain 4.0 and 5.0, as they involve the application of real-world and intelligent systems technologies that support predictive analytics and autonomous decision-making, which are important for proactive resilience. From the practitioner's perspective, these technologies improve supply chain agility and responsiveness, minimizing downtime during disruptions.
2. **Integration of Specialized Technologies**: Integration of blockchain oracles, cross-chain systems, zero-knowledge proofs (ZKPs), and secure multi-party computation (SMC) requires further research to optimize their effectiveness for modern data integration, collaboration, and privacy. These technologies provide security and scalability in managing global supply chains for industries, enabling trust and efficiency.
3. **Development of Scalable Frameworks**: There is a research gap in the design of flexible blockchain frameworks due to the limitations on transaction speed and energy consumption in current systems. Practitioners are likely to develop efficient, low-cost blockchain solutions for large-scale supply chains to alleviate these limitations.

5.1.2 Conceptual Recommendations

1. **Alignment with Resilience Stages**: Align the blockchain's critical success factors (CSFs) with the eight stages of resilience activities outlined in Table 1and Figure 1. This will allow organizations to deploy blockchain strategically at every stage and increase effectiveness. For practitioners, such frameworks are actionable and thus allow them to obtain optimal value from efforts targeted at specific investments and interventions.
2. **Maturity Models for Blockchain Adoption**: Researchers need to design maturity models to assess and guide the implementation of blockchain within SCRES, enabling organizations to measure their progress and identify gaps. The models assist practitioners in conducting an organized evaluation of readiness, setting benchmarks, and establishing standards over time.
3. **Case Study Development**: Studies on the successes and failures of implementing blockchain technology can prompt practitioners to identify successful and debatable contextual factors that determine success. This gives practitioners information on which best practices to follow and which decisions not to make.
4. **Conceptual Model**: Development of an Integrated Conceptual Model. Future research should aim to develop a comprehensive conceptual model grounded in Dynamic Capabilities Theory that integrates the identified Critical Success Factors, Challenges, and Strategies with the different stages of supply chain resilience. The core characteristics of DCT — emphasizing Sensing (identifying opportunities and threats), Seizing (mobilizing resources to capture opportunities), and Reconfiguring (transforming assets and processes for continuous adaptation) — align closely with resilience. Such a model would provide a holistic understanding of how blockchain technology strengthens these dynamic capabilities across the resilience cycle and serve as a valuable tool for both researchers and practitioners.

5. **Methodological Strengthening**: Future reviews could extend the search to additional databases, involve multiple independent reviewers in screening, quality assessment, and data extraction, and report inter-rater agreement to further enhance the reliability of the synthesis. Empirical validation of the proposed framework through case studies or expert surveys is also recommended.

5.2 Implications for Researchers and Practitioners

The proposed recommendations add unique insight for both academic scholars and professionals in the field. For scholars, the technological recommendations describe new avenues for exploiting blockchain applications, augmenting theory, and fostering interdisciplinary collaboration. The conceptual suggestions offer a set of defined scaffolds to resolve gaps in explaining blockchain's role in SCRES, bridging technology with resilience principles. For professionals, those recommendations transform attention into practical actions to enhance supply chain resilience. Businesses can control risks, improve efficiency, and remain competitive in tumultuous environments through advanced blockchain technologies and scalable frameworks. Maturity models and case studies aid in the practical demonstration of assessing readiness and learning from these applications, ensuring informed, calculated adoption without unnecessary risk. The research combines scholarly perspectives with practical industry issues, assessing how blockchain technology enhances supply chain resilience while fostering cautious yet visionary action during implementation.

Author Contributions

All authors contributed equally to the conceptualization of the article and writing of the original and subsequent drafts.

Data Availability Statement

Data available on request from the authors.

Acknowledgements

The authors would like to thank anonymous reviewers for their valuable suggestions in manuscript revision.

Ethical considerations

The authors avoided data fabrication, falsification, and plagiarism, and any form of misconduct.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Conflict of interest

The authors declare no conflict of interest.

Declaration of Generative AI

Claude AI was used solely for grammatical corrections and language editing.

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