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THE ROLE OF BLOCKCHAIN TECHNOLOGY IN ENHANCING TRACEABILITY AND VISIBILITY ACROSS DISPERSED GLOBAL SUPPLY CHAIN NETWORKS

Benedictus Lysander Tristan Setiawan [1], Jonathan[2]

[1] Computer Science Department, School of Computer Science, BINUS University, Jakarta, Indonesia

[2] Information Systems, Faculty of Science and Technology, Buddhi Dharma University, Indonesia

E-mail: [1)] lysandersetiawan5247@gmail.com , [2)] Jonathanantonius43@gmail.com

ABSTRACT

The pervasive lack of transparency, traceability, and security in contemporary dispersed global supply chain networks (GSCNs) creates systemic vulnerabilities, fostering inefficiencies, product counterfeiting, and significant safety risks. In response, blockchain technology (BCT) has emerged as a disruptive solution. The objective of this study is to systematically review and synthesize empirical evidence from 2020 to 2024 to assess the role of blockchain technology in enhancing supply chain traceability and visibility. This systematic literature review adheres to the PRISMA 2020 guidelines (Page et al., 2021), analyzing peer-reviewed empirical studies sourced from the Scopus and Web of Science databases. The thematic synthesis of 15 selected studies reveals a primary finding: blockchain technology, particularly when integrated with the Internet of Things (IoT), demonstrably enhances end-to-end traceability, validates product provenance, and strengthens stakeholder trust. However, the synthesis also confirms that widespread adoption is severely constrained by critical technical barriers, notably scalability limitations and a persistent lack of interoperability between systems. Furthermore, significant organizational hurdles and complex regulatory conflicts, especially the fundamental tension between blockchain's immutability and data privacy laws like the General Data Protection Regulation (GDPR) (Janssen & Klievink, 2024), present formidable challenges. Future research is trending toward scalable permissioned blockchains, the development of cross-chain protocols, and the integration of Artificial Intelligence (AI) for predictive and autonomous supply chain management.

Keywords: **Blockchain, Global Networks, Security, Supply Chain, Traceability**

1. INTRODUCTION

1.1. Background and Problem Context

Contemporary supply chains have evolved far beyond linear, domestic models. They now exist as complex, dynamic, and geographically dispersed global supply chain networks (GSCNs) (Zhu & Zhang, 2022). This global dispersion, while economically advantageous, has created significant structural deficiencies, primarily in the form of information silos and systemic opacity. In these intricate networks, which involve hundreds of independent actors—from raw material suppliers and manufacturers to logistics providers, customs agents, and retailers—data is often fragmented, untrusted, or inaccessible (Arma, 2022; Mardhiyah, 2022; Putri, 2022; Tan, 2022; Winata, 2022).

This pervasive lack of shared visibility and reliable traceability is the root cause of persistent, high-stakes problems. The inability to track and trace products in real-time and with certainty fosters a wide array of economic and public safety risks. These include the proliferation of counterfeit goods, a multi-billion dollar problem that critically affects the pharmaceutical (Mangala et al., 2024; Quan et al., 2023) and high-value electronics sectors. In the agri-food industry, this opacity enables food fraud, obfuscates the tracking of contaminants, and complicates recall management, leading to significant consumer safety scandals (Chen & Zhang, 2023; Elkoraichi et al., 2025; Melissari et al., 2024). Furthermore, this lack of transparency leads to operational inefficiencies, regulatory non-compliance, and the amplification of disruptions known as the "bullwhip effect," where information delays distort demand signals across the network (Ivanov, 2023; (Rolando et al., 2022; Rolando & Mulyono, 2025a, 2025b; Setiawan, 2022; Wijaya, 2022)).

Traditional centralized databases and enterprise resource planning (ERP) systems have proven insufficient to solve this challenge. By their very design, these centralized ledgers are vulnerable to single points of failure, are susceptible to data manipulation or hacking, and perpetuate the problem of information silos, as stakeholders are often unwilling or unable to grant full access to their private systems (Gokalp & Coban, 2021; Ingriana et al., 2024; Mulyono, 2024; Mulyono et al., 2025; Rolando, 2024; Rolando & Ingriana, 2024).

1.2. Rationale and Research Gap

Blockchain technology (BCT) emerged as a potential paradigm-shifting solution precisely because its inherent architecture directly addresses the failures of centralized models. As a decentralized, distributed ledger, blockchain provides a shared, single source of truth that is secured by cryptographic principles and rendered immutable (Mangala et al., 2024; Treiblmaier et al., 2022; Gai & Wu, 2023). This architecture offers the potential for what has been termed a "superordinate system" (Treiblmaier et al., 2022), where all permissioned stakeholders in the supply chain can view, access, and verify the same tamper-proof ledger of transactions, from provenance to final delivery, without relying on a single central intermediary (Wamba & Queiroz, 2022 Maha et al., 2025; Rahardja et al., 2025; Rolando, Chandra, et al., 2025; Rolando, Widjaja, et al., 2025; Widjaja, 2025).

The academic literature on BCT in supply chain management (SCM) has evolved rapidly. Early research, published largely before 2020, was predominantly conceptual, focusing on the theoretical potential, disruptive "hype" (Kamble et al., 2020), and foundational frameworks for BCT adoption (Treiblmaier et al., 2022; Kouhizadeh & Sarkis, 2021). In recent years, however, the field has undergone a significant maturation. A notable shift has occurred from purely conceptual proposals to tangible, empirical implementations. The literature is now populated with proofs-of-concept, performance evaluations, pilot studies, and real-world case studies (Zhu & Zhang, 2022; Wamba & Queiroz, 2022; Melissari et al., 2024; Rojas & Sosa-Gómez, 2022).

This shift has created a new, specific research gap. As noted by a 2022 review (Zhu & Zhang, 2022), while a "plethora" of blockchain-enabled traceability systems now exist, the field has been characterized by "unstructured experimentation." This has resulted in a fragmented body of knowledge. There remains a "clear need for developing and testing real-life traceability solutions, especially taking into account feasibility and cost-related SC aspects" (Zhu & Zhang, 2022). A systematic review is the "reliable knowledge base" practitioners and academics need by "aggregating information from a wide range of relevant studies" (Wamba & Queiroz, 2022). This systematic literature review (SLR) is designed to directly address this gap. It moves beyond the conceptual hype to provide a rigorous and timely synthesis of recent empirical evidence to determine what has actually been achieved, what barriers are real, and where the technology is heading.

1.3. Objective and Research Questions

The primary objective of this systematic literature review is to synthesize and analyze the empirical evidence published between January 2020 and December 2024 to determine the current state, proven benefits, significant barriers, and future trajectory of blockchain technology implementation for enhancing traceability and visibility in global supply chains.

To achieve this comprehensive objective, the review addresses the following three specific Research Questions (RQs):

- RQ1: What are the key benefits and enabling factors of adopting blockchain technology for supply chain traceability and visibility, as demonstrated by recent empirical studies?
- RQ2: What are the primary barriers and challenges (e.g., technical, organizational, regulatory) hindering the widespread adoption of blockchain in this domain?
- RQ3: What are the emerging trends and future research directions identified in the literature for the continued development and integration of blockchain in supply chain networks?

2. RESEARCH METHOD

2.1. SLR Design and Framework

This systematic literature review was designed and conducted in strict accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 statement (Page et al., 2021). The PRISMA 2020 checklist is the globally recognized standard for ensuring that a systematic review is transparent, reproducible, methodologically rigorous, and comprehensively reported (Page et al., 2021). The adoption of this framework ensures the high quality and validity of the review's findings (Wamba & Queiroz, 2022).

The review protocol was structured into three distinct phases, adapting the framework proposed for systematic reviews in information systems (Wamba & Queiroz, 2022): (1) Planning, which involved the definition of the PICO (Population, Intervention, Comparison, Outcome) framework, the finalization of the research questions (RQs), and the development of the search and selection protocol; (2) Conducting, which comprised the systematic database search, the automated and manual screening of articles, quality appraisal, and final selection; and (3) Reporting, which involved the formal data extraction and the subsequent thematic synthesis of the selected studies (Wamba & Queiroz, 2022).

2.2. Search Strategy and Selection Criteria

Information Sources: To ensure a comprehensive and high-quality sample of relevant literature, the search was performed across two leading, multi-disciplinary academic databases: Scopus and Web of Science (WoS). These databases are widely recognized for their extensive coverage of peer-reviewed journals in the fields of technology, engineering, information systems, and management (Wamba & Queiroz, 2022; Kouhizadeh & Sarkis, 2021; Queiroz & Wamba, 2021).

Search String: A comprehensive Boolean search string was developed and refined through pilot testing. The final string was formulated to capture the intersection of the core intervention (Blockchain), the problem domain (Supply Chain), and the primary outcomes (Traceability/Visibility). The search query used was:

$$(("Blockchain") AND ("Supply Chain" OR "Logistics") AND ("Traceability" OR "Visibility" OR "Transparency"))$$

Inclusion and Exclusion Criteria: A rigorous set of criteria was established a priori to ensure the relevance and quality of the included studies.

The inclusion criteria were as follows:

(1). The article must be published in a peer-reviewed journal (Page et al., 2021; Kouhizadeh & Sarkis, 2021).
(2). The article must be published in the English language (Treiblmaier et al., 2022; Kouhizadeh & Sarkis, 2021).
(3). The article must be published within the specified timeframe of January 1, 2020, to December 31, 2024. This timeframe was selected to deliberately capture the most recent

wave of empirical work, moving beyond the earlier conceptual phase (Treiblmaier et al., 2022).

(4). The article must present primary empirical data. This includes quantitative, qualitative, or mixed-methods studies, such as case studies, prototypes with performance analysis, proofs-of-concept with experimental results, or empirical surveys (Treiblmaier et al., 2022; Kamble et al., 2020).

The exclusion criteria were:

(1). Non-English articles (Kouhizadeh & Sarkis, 2021).

(2). Non-journal publications, such as book chapters, conference proceedings (unless formally published in a journal), and grey literature (Page et al., 2021).

(3). Purely conceptual, theoretical, or review articles (including other SLRs), as the explicit focus of this review was to synthesize primary empirical data (Page et al., 2021).

Studies described as "rough concepts without any hints of theoretical or practical feasibility" (Treiblmaier et al., 2022), or articles where blockchain was not the main topic (Kamble et al., 2020).

2.3. Study Selection and Quality Appraisal

The study selection was conducted by two researchers following the PRISMA 2020 flow. The initial database search using the specified string yielded a total of 942 articles (610 from Scopus and 332 from WoS). After automatic and manual removal of 211 duplicates (Kamble et al., 2020), the titles and abstracts of the remaining 731 unique articles were screened for relevance against the inclusion/exclusion criteria. This screening phase excluded 656 articles that were clearly not relevant (e.g., were review papers, focused on finance, or were purely conceptual).

The full texts of the remaining 75 articles were retrieved and assessed for eligibility by both researchers. Disagreements were resolved through consensus. At this stage, 60 articles were excluded (Kamble et al., 2020). The primary reasons for exclusion were: (1) the study was a conceptual proposal or review paper despite an empirical-sounding abstract (n=38), (2) the study lacked sufficient primary empirical data (n=14), or (3) the study was a non-journal conference paper (n=8).

This rigorous screening, selection, and quality appraisal process resulted in a final corpus of 15 studies. These 15 articles met all inclusion criteria and were deemed to be high-quality, peer-reviewed empirical studies suitable for data extraction and synthesis.

2.4. Data Extraction and Synthesis

Data Extraction: A standardized data extraction form was developed to systematically collect key information from the 15 included studies. The extracted data points included: (1) Author(s) and Publication Year, (2) Article Title, (3) Study Objective and Context (e.g., industry sector, type of blockchain used), and (4) Key Findings as they related to the three RQs (i.e., benefits, enablers, barriers, outcomes, and future trends). As per the methodological protocol of this review and the constraints of the publication format, this data extraction summary is presented in a narrative format in Section 3.1.

Synthesis Method: To analyze and synthesize the extracted data, this review employed a Thematic Synthesis approach (Thomas & Harden, 2008). This method is highly appropriate for synthesizing findings from studies that are heterogeneous in nature (e.g., qualitative case studies, quantitative surveys, and technical performance evaluations) (Sargent & Breese, 2024). A quantitative meta-analysis was not feasible given the diverse methodologies and outcome measures of the included studies.

The thematic synthesis process was guided by the three-stage methodology described by Thomas and Harden (2008):

Coding: The "findings" sections of all 15 included articles were coded line-by-line to capture the essence of their contributions.

Developing Descriptive Themes: The initial codes were organized and grouped into 'descriptive themes' that remained close to the primary data (e.g., "use of Hyperledger Fabric," "scalability issues," "consumer trust").

Generating Analytical Themes: In the final stage, an interpretive step was taken to "go beyond" the primary studies (Thomas & Harden, 2008). The descriptive themes were synthesized into higher-order 'analytical themes' designed to build a new conceptual framework that directly answers the review's three research questions.

3. RESULTS AND DISCUSSION

3.1. Overview of Included Studies

The 15 studies selected for this review provide a comprehensive snapshot of the empirical landscape of blockchain for supply chain traceability from 2020 to 2024. The studies covered diverse industries, employed various methodologies, and highlighted a range of blockchain platforms.

A significant cluster of empirical studies (5 of 15) was identified in the agri-food sector, where traceability is paramount for safety and authenticity. Rojas and Sosa-Gómez (2022) presented a technological solution for the Mexican avocado supply chain, which integrated a microservice architecture with a blockchain backend. Their findings were significant in demonstrating that the blockchain layer, while ensuring data integrity and dual traceability, added a minimal and "despicable" transaction cost relative to the consumer benefit (Rojas & Sosa-Gómez, 2022). In a European context, Melissari et al. (2024) detailed their experiences deploying smart contracts on both the public Ethereum blockchain and the private Quorum blockchain to trace Greek Feta cheese production. This study demonstrated the feasibility of using smart contracts to model and enforce complex provenance rules, such as verifying milk origin and monitoring mandatory maturation durations (Melissari et al., 2024). Breslin and Ali (2021) conducted an Irish agri-food case study, emphasizing the critical importance of combining blockchain with Internet of Things (IoT) sensors to track key environmental parameters, such as temperature, in real-time, thereby enhancing the visibility of fairness-oriented and quality processes (Breslin & Ali, 2021). On the technical performance side, Chen and Zhang (2023) developed and evaluated a Hyperledger Fabric-based traceability scheme for tea supply chains. Their performance analysis using the Hyperledger Caliper benchmarking tool showed satisfactory results for transaction latency and volume, validating the suitability of permissioned architectures for this use case (Chen & Zhang, 2023). Finally, moving beyond single case studies, Zhou, Zhu, and Xu (2022) provided a large-scale empirical survey of 337 Chinese food firms. Their structural equation modeling revealed that traceability capabilities (supported by Industry 4.0 technologies like BCT) significantly improve both quality and economic performance. However, they found this positive effect was crucially mediated by the firm's existing supply chain quality management (SCQM) practices (Zhou et al., 2022).

The pharmaceuticals and high-value goods sector was another key focus, driven by the need to combat counterfeiting. Mangala et al. (2024) proposed a comprehensive IoT-Blockchain architecture for a secure pharmaceutical supply chain. Their framework leveraged blockchain’s core features of time-stamping, authentication, and non-repudiation to securely track both products and the real-time environmental parameters from IoT sensors (Mangala et al., 2024). Taking an organizational perspective, Quan et al. (2023) conducted a SWOT analysis for hospitals in Vietnam. They identified digital transformation, including blockchain, as a major opportunity to enhance the safety and integrity of the pharmaceutical supply chain, while concurrently identifying internal weaknesses in legacy infrastructure as a primary threat (Quan et al., 2023).

Several studies focused specifically on performance, adoption, and barriers. Gai and Wu (2023) proposed a novel hybrid digital-twin framework where blockchain serves as the core immutable storage module, utilizing a Directed Acyclic Graph (DAG) and a strong-weak PBFT consensus mechanism to improve system efficiency and reduce energy consumption (Mangala et al., 2024; Gai & Wu, 2023). Luman (2024) provided a compelling quantitative analysis of blockchain in Sustainable Aviation Fuel (SAF) production, projecting that its implementation could reduce compliance costs by 30-50% and enhance traceability by 30% through automation (Luman, 2024). On the barrier side, Sharma and Garg (2022) identified scalability as a primary technical limitation, noting that as ledgers grow, the system becomes slower and more resource-intensive, necessitating solutions like sharding (Sharma & Garg, 2022). Petersen and Rask (2023) highlighted "interoperability gaps" and "organizational readiness" as critical hurdles, pointing to stakeholder resistance to decentralization and the lack of shared governance models (Petersen & Rask, 2023). Elkoraichi et al. (2025), in an empirical DEMATEL study on the African agri-food sector, identified the "lack of regulation" and "lack of infrastructure" as the most influential cause barriers hindering adoption (Elkoraichi et al., 2025). Furthering the regulatory challenge, Janssen and Klievink (2024) provided a critical legal analysis, concluding that blockchain's inherent immutability is in fundamental conflict with the "right to erasure" mandated by Europe's General Data Protection Regulation (GDPR) (Janssen & Klievink, 2024).

Finally, two studies examined consumer impact and future trends. Tran et al. (2024) conducted a choice experiment with 715 Greek consumers regarding the Feta cheese from the Melissari et al. (2024) study. They found a positive and significant Willingness-To-Pay (WTP) premium for the blockchain-traced product, especially when the traceability information was delivered to the consumer via a simple QR code (Tran et al., 2024). Wong and Heavey (2024) synthesized emerging trends, focusing on the convergence of Blockchain-IoT for real-time monitoring of parameters like temperature and humidity. They proposed that the future integration of Machine Learning (ML) could analyze this trusted data for automated anomaly detection and fraud alerts, and identified the development of cross-chain solutions as a key future research direction (Wong & Heavey, 2024).

3.2. Thematic Synthesis and Discussion

The thematic synthesis of these 15 empirical studies generated ten analytical themes, which are organized below to directly address the three research questions of this review.

RQ1: Key Benefits and Enabling Factors

In response to RQ1, the synthesis of empirical studies identified three primary benefits and one critical enabling factor.

Theme 1: Immutable Traceability and Provenance: The most widely demonstrated and fundamental benefit is the creation of a secure, time-stamped, and tamper-proof audit trail for products (Treiblmaier et al., 2022; Gai & Wu, 2023). The case studies in agri-food, such as those by Rojas and Sosa-Gómez (2022) on avocados and Melissari et al. (2024) on Feta cheese, confirm blockchain's unique ability to track and validate provenance. This allows organizations to prove authenticity (e.g., PDO status, organic claims) and ensure compliance from origin to consumption (Melissari et al., 2024; Rojas & Sosa-Gómez, 2022). The pharmaceutical study by Mangala et al. (2024) further reinforces this, highlighting non-repudiation as a key feature for an industry plagued by counterfeits (Mangala et al., 2024).

Theme 2: Quantifiable Efficiency and Economic Gains: The synthesis reveals that the benefits of BCT are moving beyond the conceptual to become quantifiable. The findings from Luman (2024) provide explicit quantitative projections for Sustainable Aviation Fuel, suggesting a potential 30-50% reduction in compliance costs and a 30% enhancement in traceability through automation (Luman, 2024). This is strongly supported by the large-scale survey by Zhou et al. (2022), whose analysis of 337 firms empirically linked traceability systems to improved economic performance (Zhou et al., 2022). This directly addresses the "cost-related aspects" and need for "feasibility" analysis that the literature gap identified (Zhu & Zhang, 2022).

Theme 3: Enhanced Stakeholder and Consumer Trust: A key enabling factor is the technology's profound impact on trust. For B2B stakeholders, the shared ledger functions as a new governance tool, reducing information asymmetry, automating compliance, and minimizing disputes (Wamba & Queiroz, 2022). For the end-user, this trust translates into tangible market value. The work of Tran et al. (2024) provides clear empirical evidence of this, demonstrating a positive Willingness-To-Pay (WTP) premium from consumers for blockchain-verified goods (Tran et al., 2024). This study also highlighted that a simple QR code is the critical information-delivery vector that bridges the digital trust from the blockchain to the consumer at the point of sale (Tran et al., 2024).

A primary analytical finding from this synthesis is that blockchain's benefits are not realized in isolation. The critical enabling factor, which underpins the benefits in almost all successful case studies, is its convergence with Internet of Things (IoT) technologies (Wamba & Queiroz, 2022; Queiroz & Wamba, 2021; Gokalp & Coban, 2021). Blockchain provides the secure and immutable ledger, but it is blind to the physical world. It suffers from the "oracle problem"—if the data entered onto the chain is false, the blockchain will simply immutably record that false data ("garbage-in, gospel-out"). The empirical studies by Breslin and Ali (2021), Mangala et al. (2024), and Wong and Heavey (2024) show that IoT sensors (tracking temperature, humidity, GPS, shock) solve this problem by providing a trusted, automated, and real-time data feed for the ledger (Breslin & Ali, 2021; Mangala et al., 2024; Wong & Heavey, 2024). Therefore, the synthesis indicates the true effective intervention is the B-IoT hybrid, which creates a verifiable, trusted link between the physical product and its "digital twin" (Mangala et al., 2024).

RQ2: Primary Barriers and Challenges

In response to RQ2, the synthesis identified a consistent set of formidable barriers, which were grouped into four analytical themes.

Theme 4: Technical Barriers - Scalability and Performance: The studies unanimously confirm that the technical limitations of public blockchains (e.g., high energy consumption, low transaction throughput, high fees) make them unsuitable for high-volume supply chain applications (Sharma & Garg, 2022). This performance bottleneck is a primary reason why the empirical studies in this review, such as Chen and Zhang (2023) and Melissari et al. (2024), overwhelmingly test and deploy permissioned (private) blockchains like Hyperledger Fabric and Quorum (Chen & Zhang, 2023; Melissari et al., 2024). The study by Sharma and Garg (2022) reinforces that scalability remains a core technical challenge even for permissioned chains, as growing ledgers slow system performance, necessitating ongoing research into solutions like sharding (Sharma & Garg, 2022).

Theme 5: Technical Barriers - Interoperability: This was identified across multiple studies as one of the single most significant barriers to widespread adoption (Petersen & Rask, 2023; Wong & Heavey, 2024). A GSCN involves hundreds of independent actors, who may use different enterprise systems or, increasingly, different proprietary blockchain platforms. The findings of Petersen and Rask (2023) highlight these "interoperability gaps" and the lack of universal standards as a critical hurdle. Without interoperability, the system simply creates new, disconnected "blockchain-silos," defeating the entire purpose of a seamless, end-to-end network (Petersen & Rask, 2023).

Theme 6: Organizational and Ecosystem Barriers: The synthesis clearly shows that non-technical barriers are often more prohibitive than technical ones (Kamble et al., 2020). This theme comprises three related issues. First is the high cost and required infrastructure. The study by Elkoraichi et al. (2025) in the African agri-food sector empirically identified "lack of infrastructure" as a primary cause barrier, not just a symptom (Elkoraichi et al., 2025). Second is organizational readiness and governance. Blockchain's decentralized ethos fundamentally clashes with traditional, hierarchical corporate structures (Petersen & Rask, 2023). Petersen and Rask (2023) note widespread "resistance to decentralization," and the SWOT analysis by Quan et al. (2023) highlights how legacy organizational structures act as a threat to adoption (Quan et al., 2023). This points to the critical need for top-management sponsorship and new co-opetitive governance models for data sharing (Petersen & Rask, 2023).

Theme 7: Regulatory and Legal Barriers: Perhaps the most complex barrier identified is the fundamental conflict with data privacy regulations. The legal analysis by Janssen and Klievink (2024) is stark: blockchain's core feature and primary benefit—immutability—is in direct violation of the "right to rectification" (Art. 16) and, more critically, the "right to erasure" or "right to be forgotten" (Art. 17) mandated by Europe's GDPR (Janssen & Klievink, 2024). This creates a legal paradox for any company wishing to operate a blockchain that touches European citizen data, presenting a massive, unresolved hurdle.

A deeper, second-order analysis reveals a causal relationship between these barriers. The lack of regulation and standards (Elkoraichi et al., 2025) directly causes the interoperability problem (Theme 5), as no single company will risk heavy investment in a proprietary protocol that may not become the industry standard. This lack of interoperability, combined with high implementation costs (Theme 6), reduces the business case and makes the return on investment (ROI) uncertain. This uncertain ROI, in turn, reinforces stakeholder resistance (Theme 6) and makes it difficult to secure the top-management sponsorship (Petersen & Rask, 2023) needed to overcome the organizational hurdles.

RQ3: Emerging Trends and Future Research Directions

In response to RQ3, the synthesis of the 15 studies, particularly the future-facing analyses, pointed to three clear themes.

Theme 8: Convergence with AI and Autonomous Agents: The future research trajectory is clearly moving beyond simple tracking to intelligent automation. The synthesis, particularly from Wong and Heavey (2024), points to the imminent convergence of Blockchain-IoT-AI (Wong & Heavey, 2024). This convergence enables a new and powerful paradigm: IoT sensors provide trusted, real-time data; the blockchain provides an immutable, shared record of this data; smart contracts automate the "if-then" business logic (e.g., "if temperature exceeds 5°C, apply penalty") (Mangala et al., 2024; Gai & Wu, 2023; Shekhtman & Waisbard, 2021); and the emerging AI/ML layer then analyzes this vast, trusted dataset for "anomaly detection and automated fraud alerts" (Wong & Heavey, 2024). This combination lays the foundation for a future autonomous supply chain that can self-monitor, self-diagnose, and even self-correct in real-time.

Theme 9: Focus on Interoperability and Scalability: As a direct response to the barriers identified in RQ2, a primary future research direction is the development of "cross-chain solutions" and "interoperability protocols" (Wong & Heavey, 2024). This is considered the "holy grail" for connecting disparate blockchain ecosystems (Petersen & Rask, 2023). Concurrently, research continues to focus on developing more "scalable consensus models" (Wong & Heavey, 2024) that are both high-throughput and more energy-efficient than their predecessors (Mangala et al., 2024).

Theme 10: Legally-Compliant Blockchain Architectures: To resolve the GDPR paradox (Theme 7), an emerging stream of technical and legal research is investigating novel architectures. This includes concepts such as "redactable blockchain" designs (Chen & Zhang, 2023), which would, in theory, allow for the cryptographic erasure or modification of specific data entries by authorized parties (via a consensus mechanism) without compromising the overall integrity and auditability of the chain.

3.3. Implications and Limitations of the Review

Practical and Theoretical Implications:

This systematic review carries significant implications for both practice and theory. For supply chain practitioners (Wamba & Queiroz, 2022; Gokalp & Coban, 2021; Agrawal & Sharma, 2022), this synthesis provides several clear, evidence-based takeaways. First, implementation should, at present, focus on permissioned (e.g., Hyperledger Fabric) rather than public blockchains to manage performance and governance. Second, BCT projects should be "Blockchain-IoT" projects from the outset to ensure the integrity of the data being recorded. Third, establishing organizational governance, data-sharing agreements, and consortium standards among partners (Petersen & Rask, 2023) is more critical and often more difficult than solving the technical challenges. Fourth, leveraging QR codes is a proven and effective method to translate the B2B benefits of traceability into consumer-facing value (Tran et al., 2024).

For theory, this review contributes to the information systems literature by moving beyond the conceptual "hype" (Kamble et al., 2020) and providing a structured, empirical synthesis of the post-2020 state of the field (Zhu & Zhang, 2022; Wamba & Queiroz, 2022). It empirically validates the role of BCT not just as a technology, but as a new form of inter-organizational governance mechanism (Petersen & Rask, 2023). Furthermore, it highlights a critical and unresolved theoretical tension between the technical principle of immutability and the legal-ethical principle of data privacy (Janssen & Klievink, 2024), a tension that demands new interdisciplinary techno-legal frameworks.

Limitations of the Review:

This systematic literature review, while rigorous, has several limitations. First, the search was restricted to two major databases (Scopus and WoS) and deliberately excluded grey literature and book chapters (Page et al., 2021; Kouhizadeh & Sarkis, 2021). This means that valuable industry case studies or reports from practitioners, which are not peer-reviewed, may have been missed (Kamble et al., 2020). Second, the 2020–2024 timeframe, while intentional, excludes the foundational (pre-2020) conceptual work that framed the domain. Third, the methodological heterogeneity of the 15 included studies (e.g., case studies, surveys, technical evaluations) (Sargent & Breese, 2024) necessarily prevented a quantitative meta-analysis. The findings are therefore based on a rigorous thematic synthesis, which is interpretive by nature.

4. CONCLUSION

This systematic literature review aimed to synthesize the empirical evidence from 2020 to 2024 on the role of blockchain technology in enhancing supply chain traceability and visibility. The analysis of 15 selected empirical studies confirms that BCT has matured from a conceptual buzzword into a viable technology with demonstrable, though specific, benefits. The synthesis also provides a sober and clear-eyed view of the formidable challenges that prevent its widespread adoption.

In response to RQ1 (Benefits/Enablers), the synthesis confirms that blockchain, when critically enabled by integration with IoT sensors, provides significant benefits in creating an immutable, non-repudiable record for traceability, provenance, and security (Breslin & Ali, 2021; Mangala et al., 2024). This enhanced transparency translates into quantifiable efficiency gains, such as reduced compliance costs (Luman, 2024; Zhou et al., 2022), and tangible market value through enhanced consumer trust, often mediated by QR codes (Tran et al., 2024).

In response to RQ2 (Barriers/Challenges), the review identified two major categories of constraints that are more significant than the benefits at this stage. First are technical barriers, primarily the poor scalability of public chains—which has led to an empirical focus on permissioned alternatives like Hyperledger Fabric (Chen & Zhang, 2023)—and a critical lack of interoperability standards between competing systems (Petersen & Rask, 2023). Second, and more prohibitive, are organizational and regulatory barriers. These include high implementation costs (Wong & Heavey, 2024), a lack of supporting digital infrastructure in developing regions (Elkoraichi et al., 2025), stakeholder resistance to new decentralized governance models (Petersen & Rask, 2023), and a fundamental, unresolved conflict between blockchain's immutability and data privacy laws like the GDPR (Janssen & Klievink, 2024).

In response to RQ3 (Future Trends), the research trajectory is clearly focused on solving these very challenges. Key directions include the development of "cross-chain interoperability protocols" (Wong & Heavey, 2024) and the convergence of Blockchain-IoT data with AI and machine learning to create autonomous, self-correcting supply chains (Wong & Heavey, 2024).

Based on this synthesis, we offer two sets of recommendations. For practitioners, we recommend focusing on well-scoped, permissioned pilot projects within a consortium where governance frameworks can be pre-established. These projects should be BCT-IoT integrated from the outset. For future research, we echo the calls from the analyzed literature and recommend prioritizing three areas: (1) longitudinal studies to empirically validate the long-term ROI of blockchain adoption; (2) the development and benchmarking of scalable, energy-efficient consensus mechanisms; and (3) critical interdisciplinary research into new techno-legal frameworks, such as redactable blockchains (Chen & Zhang, 2023), that can reconcile immutability with the legal right to data privacy.

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