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BUILDING SUPPLY CHAIN RESILIENCE: HOW BLOCKCHAIN TECHNOLOGY ADDRESSES VULNERABILITIES AND STRENGTHENS CAPABILITIES

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Purpose: This study explores the potential of blockchain technology to mitigate supply chain vulnerabilities and enhance resilience-building capabilities. Using the SCRAM framework as a foundation, it examines how blockchain features align with specific vulnerabilities and capabilities to strengthen supply chain resilience.

Design/methodology/approach: The research employs a conceptual analysis based on the SCRAM framework and blockchain technology features. By reviewing academic literature and industry case studies, the study systematically maps blockchain functionalities to the vulnerabilities and capabilities defined in SCRAM. A diagram is developed to visually illustrate these interactions.

Findings: The study identifies how blockchain features—such as transparency, decentralization, smart contracts, and immutability—address specific vulnerabilities, including process disruptions and resource constraints, while enhancing capabilities like visibility, adaptability, and collaboration. The proposed mapping highlights blockchain's dual impact on reducing risks and strengthening resilience.

Research limitations/implications: The findings are primarily theoretical, based on literature review and conceptual mapping. Empirical validation in real-world supply chains is needed to confirm the suggested relationships and measure blockchain's practical impact on supply chain resilience.

Practical implications: The study provides a framework for businesses to strategically adopt blockchain technology to address supply chain risks and enhance resilience. The mapping and accompanying diagram can serve as a decision-making tool for practitioners in designing robust supply chain strategies.

Originality/value: This research contributes to the growing literature on blockchain in supply chain management by integrating it with the SCRAM framework. The unique mapping of blockchain features to vulnerabilities and capabilities offers both theoretical insights and practical applications, paving the way for further empirical exploration and innovation.

Keywords: blockchain technology, supply chain resilience, supply chain vulnerability.

Category of the paper: Research paper.

1. Introduction

In an increasingly interconnected and volatile global economy, supply chains face unprecedented challenges, ranging from environmental turbulence and resource constraints to deliberate threats and dependency on critical partners. Addressing these vulnerabilities requires a comprehensive framework that not only identifies potential weaknesses but also outlines strategies to build resilience. Petit's Supply Chain Resilience Assessment and Management (SCRAM) framework provides a robust foundation for such an analysis, categorizing supply chain risks into 7 key vulnerabilities and offering 14 capabilities essential for resilience (Petit, 2008). Simultaneously, the emergence of blockchain technology has introduced transformative solutions to enhance transparency, security, and efficiency across supply chains. Features such as decentralization, traceability, immutability, and smart contracts have shown immense potential in mitigating risks and strengthening operational capabilities.

This article explores the intersection of these two domains, leveraging the SCRAM framework to systematically evaluate how blockchain technology can address specific vulnerabilities while bolstering resilience-building capabilities. By analyzing literature and real-world applications, it offers a conceptual mapping that connects blockchain features with elements of the SCRAM framework. The resulting diagram, "Blockchain impact on SCRAM Vulnerability factors and resilience building capabilities" illustrates the dual impact of blockchain, serving as both a theoretical model and a practical guide for businesses aiming to fortify their supply chains in an era of uncertainty.

2. Methods

The methodology adopted in this article is grounded in the integration of SCRAM framework developed by Petit with the core features and applications of blockchain technology. The following steps outline the structured approach used in the study:

1) Framework selection: The SCRAM framework was chosen as the foundational model due to its comprehensive categorization of supply chain vulnerabilities and resilience-building capabilities. It provides a robust theoretical base for analyzing the challenges and strengths inherent in supply chains.
2) Blockchain features analysis: Key features of blockchain technology, including transparency, decentralization, smart contracts, process automation, security and trust, traceability, immutability of records, and process standardization, were examined in detail. These features were identified through an extensive review of relevant literature and practical applications across various industries.

3) Mapping Blockchain to SCRAM: A systematic process was undertaken to align blockchain features with the 7 vulnerability factors and 14 capabilities defined in SCRAM. This involved:
   - Identifying how specific features of blockchain mitigate or address each vulnerability.
   - Exploring how these features simultaneously enhance resilience capabilities, such as adaptability, collaboration, and recoverability.
4) Literature Review: The analysis was supported by a thorough review of academic publications, industry case studies, and reports that provided evidence of blockchain's practical applications and its impact on supply chain management. This ensured that the proposed alignments were grounded in empirical and theoretical research.
5) Visual Representation: As a primary outcome of the study, a comprehensive diagram was developed: "Blockchain impact on SCRAM vulnerability factors and resilience building capabilities". This diagram visually encapsulates the dual impact of blockchain features, showing their role in mitigating vulnerabilities and enhancing capabilities.

This methodology provides a structured approach to integrating blockchain technology into the SCRAM framework, offering both theoretical insights and practical implications for enhancing supply chain resilience. The combination of literature-based analysis and conceptual mapping ensures that the findings are both academically rigorous and actionable in real-world contexts.

3. The SCRAM framework and blockchain core features

The SCRAM framework

In 2008, T. Petit presented a tool for analyzing the resilience of supply chains. This tool was called the "Supply Chain Resilience Assessment and Management" (SCRAM) and consisted of using a survey form consisting of statements' series regarding the vulnerability and resilience of the supply chain, with which the respondents assessed compliance on a five-point Likert scale (Petit, 2008).

The statements regarding the vulnerability and resilience of the supply chain were arranged in the framework of 7 "vulnerability factors" of the considered supply chains and 14 supply chain capabilities (Petit et al., 2010). The vulnerability factors of the supply chain are defined in Table 1. In the area of each of the seven vulnerability factors, it is possible to assess more detailed elements influencing the assessment of the analyzed supply chain in terms of its vulnerability.

Table 1.
SCRAM's vulnerabilities description

ID	Vulnerability factors	Description
V1	Turbulence	The environment is exposed to frequent changes in external factors beyond the company's control
V2	Deliberate threats	There are intentional attacks aimed at disrupting operations or causing human, material and financial damage
V3	External pressures	There are external tensions causing business disruptions
V4	Resource limits	There are limitations due to the lack of availability of resources for production and distribution
V5	Sensitivity	The importance of strictly controlling the conditions of the processes and materials used
V6	Connectivity	The degree of dependence on external partners
V7	Supplier/Customer disruptions	The vulnerability of suppliers and buyers to external disruptions

Source: own elaboration based on Pettit, Fiksel, Croxton, 2010, pp. 1-21.

The second part of the SCRAM tool refers to the ability of the supply chain to build and strengthen resilience. Its author indicated 14 such capabilities. Each of them could be called a strategy for building resilience, as it emphasizes a certain set of actions that can influence the supply chain resilience strengthening. The individual capabilities are presented in Table 2.

Table 2.
Supply chain's resilience building capabilities

ID	SC resilience building capabilities	Description
C1	Flexibility in Sourcing	Ability to quickly change supply sources
C2	Flexibility in Order Fulfilment	The ability to quickly change means of transport or other factors related to order fulfillment
C3	Capacity	Availability of resources to ensure a certain level of production
C4	Efficiency	The ability to produce with minimal resource requirements
C5	Visibility	Knowledge of the condition of operational assets and the environment
C6	Adaptability	Ability to modify operations in response to threats and opportunities
C7	Anticipation	The ability to perceive potential future events or situations
C8	Recovery	The ability to quickly return to normal after a disruption
C9	Dispersion	Wide distribution or decentralization of assets
C10	Collaboration	Ability to work effectively with external entities for mutual benefit
C11	Organization	Human resource structures, policies, skills and culture
C12	Market position	Company status on the market
C13	Security	The ability to protect against external attacks and other threats
C14	Financial strength	Ability to absorb fluctuations in cash flow

Source: own elaboration based on Pettit, Fiksel, Croxton, 2010, pp. 1-21.

Within each of the 14 capabilities, it is possible to assess more detailed elements influencing the assessment of the analyzed supply chain in terms of its resilience. In the following sections of this article, SCRAM's elements are paired with key features of blockchain technology to highlight its potential for creating and strengthening the resilience of modern supply chains (Zaczyk, 2019).

Blockchain core features

Blockchain technology has emerged as a transformative solution in various industries, including supply chain management, due to its unique set of features that directly address operational inefficiencies, vulnerabilities, and the need for resilience (Dutta et al., 2020). This section explores the key features of blockchain technology and their applications, focusing on transparency, decentralization, smart contracts, process automation, security and trust, traceability, immutability of records, and process standardization.

Blockchain's transparency stems from its distributed ledger system, where all participants in the network have access to the same, verified data (Sedlmeir et al., 2022). This feature reduces information asymmetry, enabling stakeholders to make informed decisions. In supply chains, transparency ensures real-time visibility into inventory levels, shipment status, and supplier compliance (Sunny et al., 2020). For example, food manufacturers use blockchain to provide consumers with detailed information about product origins, ensuring accountability and fostering trust. Unlike centralized systems, blockchain operates on a decentralized network where no single entity has control (Zarrin et al., 2021). This eliminates the risks associated with single points of failure and enhances resilience. In supply chain contexts, decentralization allows diverse stakeholders - such as manufacturers, logistics providers, and retailers - to interact on equal terms, improving collaboration and reducing dependency on intermediaries (Naef et al., 2024).

Smart contracts are self-executing agreements encoded on the blockchain that automatically trigger actions when predefined conditions are met (Turner, 2021). This feature streamlines complex processes, such as payment settlements, order fulfillment, and regulatory compliance (Sigalov et al., 2021). For instance, in trade finance, smart contracts can automate payments upon the successful delivery of goods, minimizing delays and disputes (Aránguiz et al., 2021). Blockchain enables process automation by integrating smart contracts with other digital systems (Eggers et al., 2021). This reduces manual intervention, improves efficiency, and eliminates human errors. Applications include automated inventory replenishment and route optimization in logistics, where blockchain ensures seamless coordination across multiple stakeholders (Ran et al., 2024). Blockchain's cryptographic protocols and consensus mechanisms ensure the security and authenticity of transactions (Lashkari, Musilek, 2021). Data stored on the blockchain is highly resistant to tampering, fostering trust among participants. In the pharmaceutical industry, for example, blockchain prevents counterfeit drugs from entering the supply chain by securely tracking each product's lifecycle (Musamih et al., 2021).

Once data is recorded on a blockchain, it cannot be altered or deleted without consensus from the network (Kairaldeen et al., 2021). This immutability guarantees data integrity and provides an auditable trail of transactions. For example, in logistics, immutable records ensure that shipment details cannot be fraudulently modified, enhancing accountability and reducing disputes (Selvaprabhu, 2023). Blockchain facilitates the standardization of processes by providing a common framework for data exchange and workflow management (Papadakis, Kopanaki, 2022). This is particularly useful in global supply chains, where diverse participants must adhere to varying regulations and practices. Blockchain ensures consistency, as seen in the automotive industry, where it standardizes the tracking of parts and components across international suppliers (Habibullah et al., 2024).

By leveraging these features, blockchain technology addresses long-standing challenges in supply chain management while unlocking new opportunities for efficiency, collaboration, and resilience. Its applications continue to expand, demonstrating its potential to reshape the future of supply chains and other interconnected systems.

4. Blockchain impact on SCRAM vulnerability factors and resilience building capabilities

Blockchain technology offers a unique set of features that directly address the vulnerability factors identified in the SCRAM framework, as summarized in Table 3.

Table 3.
Blockchain technology features affecting the supply chain's vulnerability factors

Vulnerability factors	Blockchain features	Examples
Turbulence	- Transparency - Traceability	Food industry: Tracking the source of contamination in the food supply chain
Deliberate threats	- Immutability of records - Security and trust	Pharmaceuticals: verification of medicine authenticity, elimination of counterfeits
External pressures	- Smart contracts utilization	International trade: automation of customs documents
Resource limits	- Transparency - Process automation	Logistics: optimizing storage and inventory management
Sensitivity	- Process standardization - Automatic data logging	Manufacturing: automation of component orders via smart contracts
Connectivity	- Transparency - Shared data ledgers	Automotive: collaboration platforms for sharing supplier and order data
Supplier/Customer disruptions	- Traceability - Trust and security	Apparel industry: real-time tracking of raw materials across supply chains

Source: own elaboration.

Environmental turbulence, characterized by unpredictable changes in supply chain conditions, can be mitigated through blockchain's real-time traceability and data immutability, ensuring accurate and up-to-date information flow across stakeholders (Horrigan, 2023). For instance, in the food industry, blockchain-enabled traceability systems allow rapid identification of affected batches during recalls, minimizing disruptions. Deliberate threats, such as fraud or cyber-attacks, are countered by the security and trust inherent in blockchain's cryptographic protocols and decentralized nature (Ahmad, David, 2024). This creates a tamper-proof ledger, exemplified in the pharmaceutical sector, where counterfeit prevention mechanisms ensure the authenticity of products. External pressures, like regulatory requirements, are addressed through smart contracts, which automate compliance checks and reduce administrative burdens (Gucciardi, 2023). A notable example is the integration of blockchain in customs clearance processes, enabling faster and error-free documentation verification.

Resource constraints, such as limited capacity or raw material shortages, benefit from blockchain’s ability to improve efficiency and adaptability through precise resource tracking and predictive analytics (Nagariya et al., 2024). Supply chain partners can optimize inventory management and reduce waste, as demonstrated in manufacturing sectors employing blockchain for just-in-time systems. For process vulnerabilities, blockchain ensures visibility and transparency, reducing errors and delays by providing a unified view of the supply chain (Madhani, 2021). In automotive logistics, blockchain platforms enhance process reliability by tracking parts' provenance and ensuring compliance with quality standards.

Dependency on partners is mitigated through blockchain’s decentralization, which reduces reliance on single points of failure (Lohmer et al., 2020). In multi-tiered supply chains, decentralized systems distribute authority and increase resilience, especially in scenarios where suppliers face disruptions. Finally, disruptions from suppliers or customers are alleviated by blockchain’s real-time visibility and immutability, allowing swift identification and resolution of bottlenecks (Etemadi et al., 2021). For example, blockchain-powered platforms in retail enable dynamic re-routing of deliveries during unforeseen events, ensuring continuity in service levels. By aligning blockchain features with specific vulnerabilities, organizations can strategically leverage this technology to fortify their supply chains against diverse risks and uncertainties.

Blockchain technology and SCRAM resilience building capabilities

Blockchain technology, on the other hand, aligns with the capabilities defined in the SCRAM framework by enhancing key supply chain functions and supporting resilience-building measures, as outlined in Table 4.

Table 4.
Blockchain technology features strengthening resilience building capabilities

Capability	**Blockchain features**
Flexibility in sourcing	- Traceability - Transparency
Flexibility in Order Fulfilment	- Process automation - Smart contracts
Capacity	- Transparency - Immutability of records
Efficiency	- Process automation - Smart contracts
Visibility	- Transparency - Immutability of records
Adaptability	- Scalability - Traceability
Anticipation	- Immutability of records - Process automation
Recovery	- Immutability of records - Decentralization
Dispersion	- Decentralization
Collaboration	- Security and trust - Transparency
Market position	- Process standardization - Immutability of records
Security	- Traceability - Security and trust
Financial strength	- Decentralization - Transparency

Source: own elaboration.

Supply flexibility, the ability to adapt sourcing strategies, is bolstered by blockchain's traceability and visibility, enabling dynamic adjustments based on real-time data. In the agricultural sector, for example, blockchain platforms allow buyers to source products from alternative suppliers during disruptions without compromising quality standards (Pattanayak et al., 2024). Order fulfillment flexibility, which ensures responsiveness to changing customer demands, is enhanced through smart contracts that automate order processing and payment workflows. Retailers leveraging blockchain can seamlessly adjust fulfillment priorities and payment terms during peak demand periods (Nadime et al., 2023).

Production asset availability, a critical component of operational continuity, benefits from blockchain's immutability and transparency, which facilitate predictive maintenance and precise asset management. For instance, in manufacturing, blockchain is used to monitor equipment health, reducing downtime and ensuring operational efficiency (Leng et al., 2020). Efficiency, a cornerstone of supply chain performance, is significantly improved through blockchain-enabled automation and decentralized data sharing, which reduce redundancies and streamline operations. Logistics companies, for instance, use blockchain to optimize route planning and minimize fuel consumption (Ran et al., 2024). Visibility, the ability to monitor the entire supply chain, is inherently supported by blockchain's transparent and real-time data-sharing capabilities. This feature is particularly impactful in industries like pharmaceuticals, where end-to-end visibility ensures compliance with regulatory standards and enhances trust among stakeholders (Uddin et al., 2021).

Adaptability, or the capacity to respond to unexpected changes, is strengthened by blockchain's flexible and decentralized structure, enabling organizations to reconfigure their networks in response to disruptions. Blockchain's role in facilitating adaptive supplier networks has been demonstrated in sectors like electronics, where supply chains must frequently adjust to component shortages. Anticipation, the ability to forecast risks and opportunities, is improved by blockchain's ability to consolidate and analyze historical data. This predictive capability allows businesses in sectors such as energy to anticipate demand fluctuations and plan resource allocation proactively (Vionis, Kotsilieris, 2023).

Recoverability, which focuses on restoring operations after disruptions, is enhanced by blockchain's secure and reliable data management, enabling accurate damage assessments and streamlined recovery efforts. For example, after natural disasters, blockchain systems in supply chains have expedited insurance claims and resource deployment. Dispersion, the ability to distribute resources and operations, benefits from blockchain's decentralization, which supports geographically diverse supply chain configurations. Organizations in global trade use blockchain to coordinate distributed warehouses and ensure operational continuity (Helo, Shamsuzzoha, 2020). Collaboration across supply chain partners is facilitated by blockchain's shared ledger system, which promotes trust and reduces friction in information exchange. The automotive industry, for instance, uses blockchain to synchronize production schedules and parts availability among suppliers (Ada et al., 2021).

Organization, or the alignment of internal processes, is supported by blockchain's ability to enforce standardized workflows through smart contracts. Market position is strengthened by blockchain's ability to enhance brand credibility through traceability and authenticity verification, particularly in industries like luxury goods and organic food production (de Boissieu et al., 2021). Finally, financial position benefits from blockchain's ability to streamline payment processes and reduce transaction costs. Organizations using blockchain-based payment systems can shorten cash conversion cycles, improving liquidity and financial resilience (Purwaningsih et al., 2024).

Mapping blockchain features to SCRAM elements

By mapping blockchain features to these capabilities and - on the other hand - to vulnerability points, businesses can strategically adopt the technology to not only enhance specific supply chain functions but also build a robust foundation for resilience and long-term competitiveness. The Figure 1 illustrates the dual role of blockchain technology in enhancing supply chain resilience.

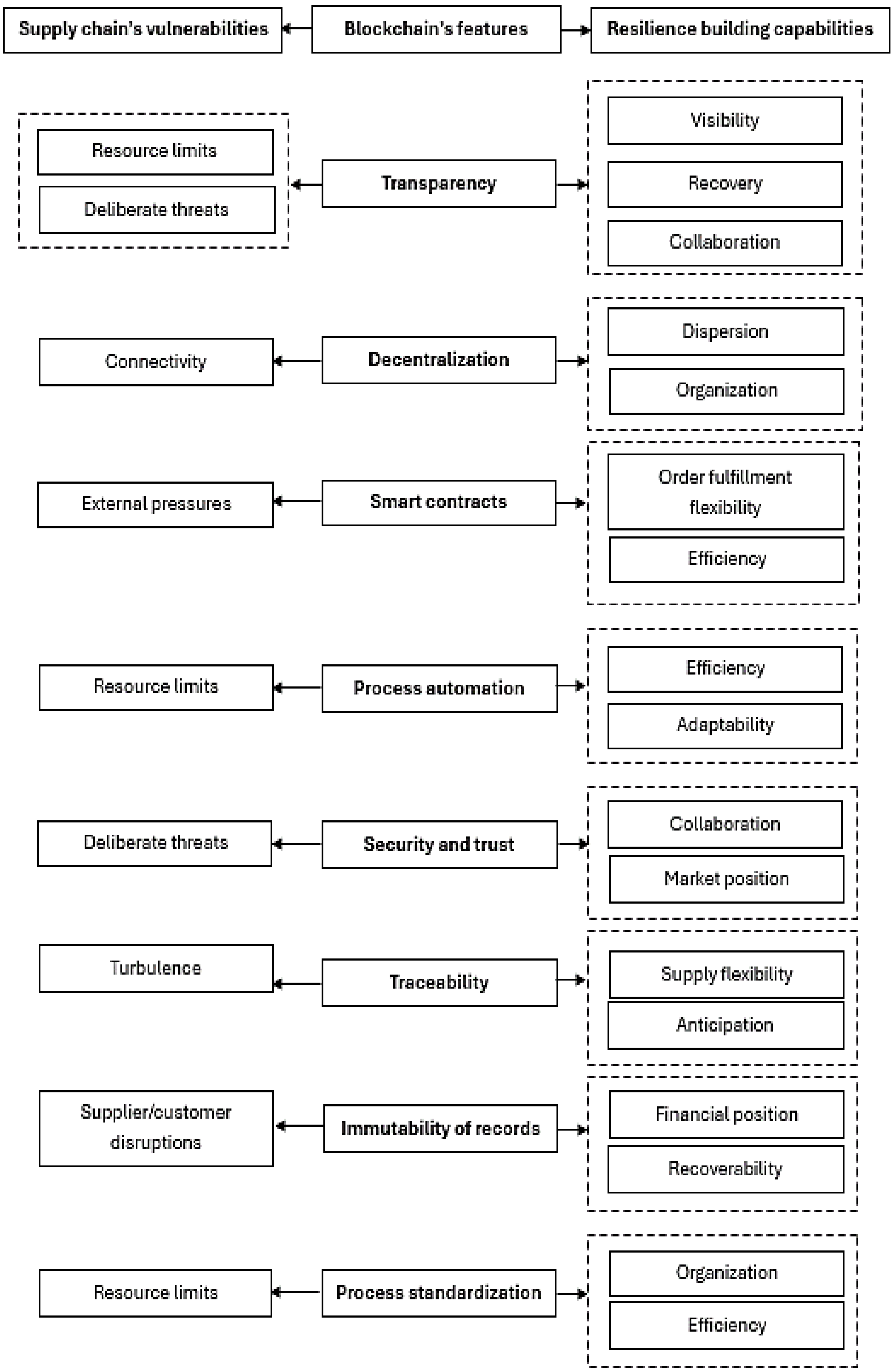

Figure 1. Blockchain impact on SCRAM Vulnerability factors and resilience building capabilities.
Source: own elaboration.

On one side, the Figure 1 highlights how specific features of blockchain—such as transparency, decentralization, immutability of records, traceability, security and trust, process automation, and smart contracts—mitigate the vulnerability factors identified in the SCRAM framework. These vulnerabilities include supplier/customer disruptions, environmental turbulence, deliberate threats, resource constraints, external pressures, dependency on partners, and process vulnerabilities. On the other side, the Figure 1 demonstrates how these blockchain features simultaneously strengthen key resilience-building capabilities within the supply chain. These capabilities include supply flexibility, order fulfillment flexibility, efficiency, collaboration, recoverability, visibility, adaptability, financial position, anticipation, and organization. The visual representation emphasizes the interconnected nature of blockchain's impact, showcasing its ability to both reduce weaknesses and enhance strengths, creating a robust and adaptive supply chain system. This dual effect underscores blockchain's critical role in transforming supply chain management for greater resilience.

5. Conclusion

This article demonstrates the potential of blockchain technology to address supply chain vulnerabilities and enhance resilience-building capabilities through the lens of the SCRAM framework. By systematically mapping blockchain features—such as transparency, decentralization, smart contracts, and immutability—to the seven vulnerabilities and fourteen capabilities outlined in SCRAM, the study highlights blockchain's dual role in mitigating risks and reinforcing operational strengths. The conceptual diagram developed as the key outcome of this research provides a practical and theoretical tool for understanding these interactions and applying them in real-world supply chains. However, while the analysis offers strong theoretical support and insights from literature and case studies, the findings raise an important question: how effectively do these theoretical linkages translate into tangible results in specific supply chain contexts? To address this, future research should focus on empirical validation of the proposed framework. Studies could investigate selected supply chains across industries to measure the real-world impact of blockchain on vulnerabilities and resilience capabilities. Such research could involve qualitative case studies, quantitative assessments, or longitudinal analyses to determine the degree to which blockchain influences supply chain performance.

Furthermore, future studies could explore how other emerging technologies—such as artificial intelligence or Internet of Things (IoT)—might interact with blockchain to create synergies in addressing supply chain vulnerabilities. By expanding the scope of research and integrating empirical evidence, scholars and practitioners can further refine the theoretical foundations and practical applications of blockchain in supply chain resilience. Ultimately, this article contributes to a growing body of knowledge on blockchain's role in supply chain management, offering a framework for both academic inquiry and business innovation. As organizations continue to navigate the complexities of global supply chains, the insights provided here can guide strategic decisions to build more robust and adaptive systems.

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