A Survey of Supply Chain Platforms Ecosystems B2B Digital Transformation and Business Networks

Abstract

This survey paper provides a comprehensive review of the transformative impact of digital technologies on supply chain management, focusing on supply chain platforms, ecosystems, B2B interactions, and digital transformation. It highlights the pivotal role of blockchain and IoT in enhancing transparency, efficiency, and security across diverse industries, facilitating decentralized trust mechanisms, and optimizing operations. The integration of business networks and collaborative platforms is underscored as essential for fostering stakeholder engagement and driving innovation. Key challenges identified include data management, trust issues, and regulatory compliance, necessitating robust frameworks and strategic partnerships. The survey emphasizes the need for interoperable systems and standardized protocols to enhance supply chain visibility and resilience. It also explores future research opportunities in advanced modeling techniques, scalable blockchain solutions, and the integration of AI and digital twins. By addressing these areas, the paper aims to advance the understanding of supply chain dynamics and foster sustainable competitive advantages in the digital age.

1 Introduction

1.1 Significance of Supply Chain Platforms and Ecosystems

Supply chain platforms and ecosystems play a critical role in enhancing operational efficiency, fostering collaboration, and maintaining product integrity across various industries. As complex adaptive systems, supply chain networks (SCNs) are susceptible to vulnerabilities that require effective modeling to enhance resilience [1]. Advanced technologies, particularly blockchain, are instrumental in addressing these challenges by providing decentralized, immutable ledgers that improve transparency and efficiency, especially in sectors such as healthcare [2].

In the Halal industry, business process reengineering is vital for resolving issues related to product authenticity and contamination, ensuring compliance with industry standards [3]. The food supply chain also grapples with inefficiencies and transparency challenges, which can be mitigated through the application of blockchain and IoT technologies, addressing unfair competition and enhancing regulatory compliance [4]. Trust and transparency are paramount in food supply systems, necessitating improved safety and efficiency.

Moreover, supply chain platforms are essential for mitigating security risks associated with IoT systems, which present unique challenges compared to traditional supply chains [5]. Despite advancements in Information and Communication Technologies (ICT) that reduce information asymmetry and enhance interorganizational collaboration, trust issues persist, impeding the sharing of sensitive data among supply chain partners [6]. The increasing vulnerability of supply chains to adversarial attacks highlights the need for effective legal frameworks at both EU and national levels to address these risks [7].

The systemic risk posed by individual companies within supply chains emphasizes the necessity of understanding and managing supply chain platforms and ecosystems [8]. In today's global

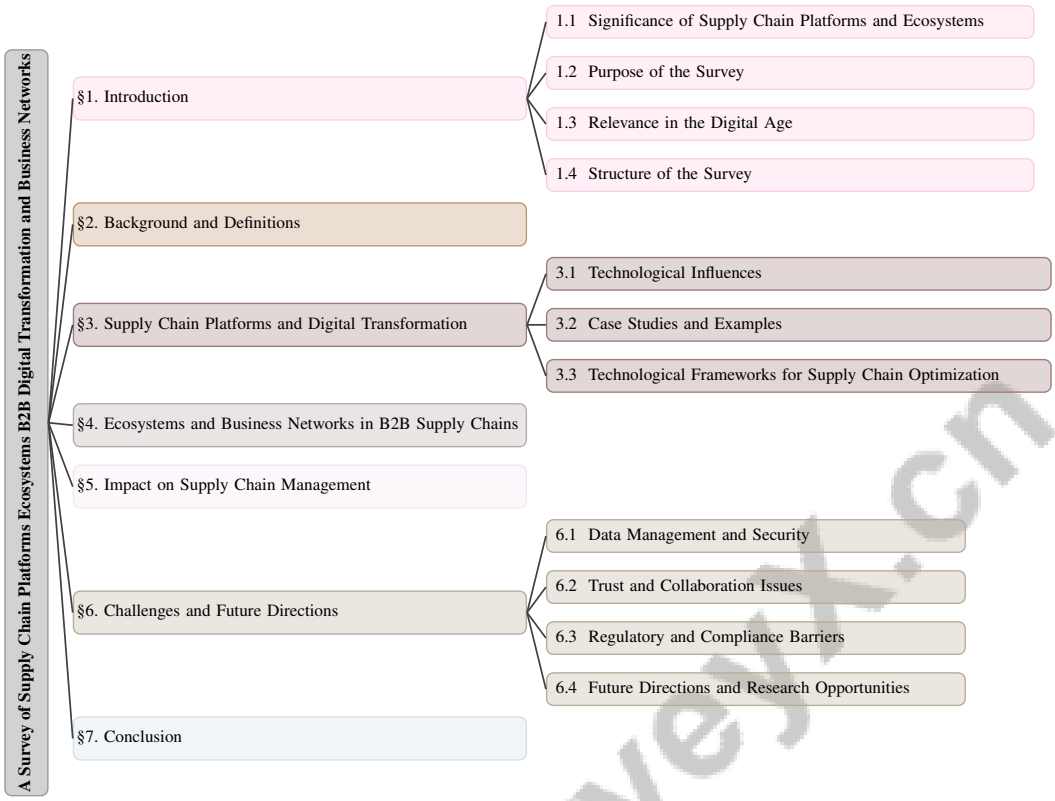

Figure 1: chapter structure

marketplace, firms compete as interconnected entities rather than isolated players, underscoring the importance of these platforms in sustaining competitive advantage [9]. Overall, supply chain platforms and ecosystems are crucial for enhancing transparency, resilience, and collaboration, driving innovation and competitiveness while adhering to regulatory compliance and sustainability standards [10].

1.2 Purpose of the Survey

This survey aims to provide a thorough review of methodologies for modeling the topology and robustness of Supply Chain Networks (SCNs) through the lens of network science, addressing existing knowledge gaps and enhancing our understanding of supply chain dynamics [11]. It investigates information exchange practices and collaboration trends that improve supply chain performance, particularly in the context of digital technologies [12].

A significant focus is placed on supply chain risks within IoT systems, exploring research challenges related to supply chain security and identifying future research directions [5]. The survey also examines blockchain applications to enhance traceability and transparency in regulated environments, such as the food supply chain and the International Healthcare Supply Chain (IHSC).

Additionally, the survey addresses the challenges faced by e-commerce and process industries in managing global supply chains, highlighting the need for scalability, integration, and effective decision-making [13]. It seeks to improve supply chain transparency by developing a collaborative platform for centralizing multi-tier supply chain information [10].

By tackling the prevalence of non-genuine Halal products and the associated consumer trust issues, the survey emphasizes the importance of ensuring quality and compliance [3]. Furthermore, it evaluates the risk of bankruptcy for Small and Medium Enterprises (SMEs) stemming from supply chain uncertainties, proposing solutions for optimizing network design to minimize costs and delivery delays.

The survey aspires to foster innovation, enhance security, and improve competitiveness across industries by leveraging digital technologies such as blockchain and IoT in supply chain management. It addresses critical aspects, including the need for robust cybersecurity measures to safeguard data integrity and assets, as well as the technological infrastructure necessary to overcome implementation challenges in the evolving landscape of digital supply chains [14, 15].

1.3 Relevance in the Digital Age

In the digital era, the transformation of supply chains is closely tied to the integration of advanced technologies that enhance agility, efficiency, and sustainability. The adoption of Industry 4.0 (I4.0) technologies, including blockchain and digital twins, is crucial for facilitating digital transformation by improving security and operational efficiency within modern supply chains. The rising importance of last-mile logistics, particularly in pharmaceuticals, underscores the trend towards home medication delivery, necessitating improved supply chain capabilities [16].

Blockchain technology is particularly relevant for improving food security, safety, and integrity, while also supporting small farmers, thereby advancing agricultural supply chains. It is also pivotal in combating counterfeit products, as seen in the wine industry, where verifying product authenticity poses significant challenges [17]. Implementing a blockchain-based food supply chain management system can significantly enhance efficiency, transparency, and traceability [18].

Traditional supply chains, often characterized by manual processes and error-prone practices, require a shift towards automation and self-decision-making capabilities to maintain competitiveness in the digital landscape [19]. This transition is bolstered by the integration of big data analytics, which bridges the gap between traditional forecasting methods and the demands of contemporary supply chain environments [20]. The need for improved accountability and traceability through blockchain integration highlights the importance of digital transformation in modernizing supply chain practices [21].

Furthermore, the lack of information sharing and cooperation among logistics actors, exacerbated by data confidentiality challenges, underscores the necessity for innovative cooperative logistics information systems [22]. Adopting standardized technologies to ensure platform, vendor, and language independence addresses many challenges in supply chain management [23]. Collectively, these elements emphasize the critical importance of digital transformation in fostering sustainable competitive advantages and optimizing supply chain dynamics in the digital age [24].

The relevance of this topic is further highlighted by the complexities and vulnerabilities of Supply Chain Networks (SCNs) amid digital transformation and the need for robust modeling techniques [11]. The survey focuses on the implementation challenges of digital supply chains, particularly concerning IoT technology, emphasizing its significance in the digital transformation landscape [15]. Additionally, the importance of data governance in enhancing data usability and decision-making processes, especially in manufacturing, is critical in the digital age [25]. The urgent demands of International Healthcare (IH) practitioners and regulators for improved supply chain safety and compliance further underscore the significance of this topic [26].

1.4 Structure of the Survey

This survey is systematically organized to provide a comprehensive exploration of interconnected themes related to supply chain platforms, ecosystems, B2B interactions, digital transformation, and business networks. The paper is structured into distinct sections, each addressing key themes and methodologies relevant to supply chain management and operations, including an overview of supply chain principles, logistics roles, psychological traits in professionals, and advancements in information sharing and technology applications [27, 28, 24, 29, 30].

The following items outline key aspects of supply chain management, emphasizing the role of logistics, the impact of global dimensions, and the innovative application of large language models (LLMs) to enhance the understanding and mapping of complex supply chain networks, particularly in the civil engineering sector [30, 24].

- **Introduction:** This section introduces the overarching themes and significance of the survey, establishing the foundational importance of supply chain platforms and ecosystems

in modern business environments, elucidating the survey's purpose, and underscoring its relevance in the digital age.

- **Background and Definitions:** The second section provides a detailed overview of core concepts such as supply chain platforms, ecosystems, B2B, digital transformation, and business networks, defining each term and exploring their interconnections and relevance in contemporary supply chain management.
- **Supply Chain Platforms and Digital Transformation:** This section delves into how digital platforms are revolutionizing supply chain management, discussing technological influences and providing case studies of successful digital transformation initiatives. It also explores technological frameworks like blockchain, digital twins, AI, and IoT for optimizing supply chains.
- **Ecosystems and Business Networks in B2B Supply Chains:** This section examines ecosystems and business networks in B2B supply chains, discussing collaboration models and stakeholder engagement while analyzing the benefits and challenges of building and maintaining such networks [22].
- **Impact on Supply Chain Management:** The fifth section analyzes the impact of digital transformation, platforms, ecosystems, and business networks on supply chain management practices, exploring how these elements contribute to improved competitiveness, agility, and resilience in supply chains [24].
- **Challenges and Future Directions:** This section identifies key challenges organizations face in implementing and managing digital platforms, ecosystems, and business networks, discussing potential future trends and research directions, including data management and security, trust and collaboration issues, and regulatory and compliance barriers.
- **Conclusion:** The final section summarizes the key findings of the survey, highlights the importance of integrating digital platforms, ecosystems, and business networks in supply chain management, and suggests practical implications and future research opportunities.

This structured approach facilitates a comprehensive analysis of the intricate and evolving interactions within contemporary supply chains, illuminating their transformation and optimization in the digital era. By examining the impact of technology-enabled networking and collaborative strategies, it highlights the shift from traditional cost-focused procurement to value creation, the significance of traceability for effective logistics management among diverse stakeholders, and the demand for specific psychological traits in operations and supply chain professionals, ultimately providing actionable insights for enhancing supply chain performance and resilience in a competitive landscape [31, 32, 28].The following sections are organized as shown in Figure 1.

2 Background and Definitions

2.1 Core Concepts and Definitions

The optimization of modern supply chain management relies on key concepts that boost operational efficiency and transparency. The Industrial Internet of Things (IIoT) provides substantial benefits but also introduces cyber risks, necessitating robust risk management, particularly in healthcare, where blockchain enhances security and efficiency [2]. Blockchain, as a decentralized ledger, is crucial for improving traceability and efficiency, especially when integrated with IoT for hyperconnected logistics and smart contracts.

Supply chains, recognized as complex, non-linear systems, require innovative modeling to address their multifaceted nature. Predicting unknown supplier-customer relationships is vital for comprehensive risk assessment [8]. The interconnectedness of supply chains necessitates sophisticated modeling, as shown by the systemic risk from lacking firm-level transaction data [8].

Decentralized solutions like blockchain platforms are integral to modern supply chain management, addressing trust and authenticity issues, particularly in counterfeit-prone industries [33]. Collaborative forecasting, involving information sharing on demand and supply, is crucial for operational planning and mitigating inefficiencies among partners [34].

Supply chain transparency, defined as accessing and disclosing supplier information across tiers, is essential for enhancing dynamics [10]. The food supply chain faces transparency and traceability

challenges, leading to safety risks and fraud, which blockchain can mitigate by improving traceability. IoT supply chain security vulnerabilities, characterized by complexity and decentralization, require effective security measures [7].

Managing supply chains in e-commerce and process industries highlights the need for advanced strategic frameworks for decision-making and efficiency [13]. Optimizing networks—comprising suppliers, manufacturing plants, distribution centers, and retailers—requires hierarchical cost functions to analyze and optimize performance under uncertainty. These concepts illustrate the transformative potential of digital technologies in enhancing efficiency, transparency, and sustainability across industries, facilitating a fundamental shift in supply chain dynamics.

2.2 Interconnections and Relevance

The interconnectedness of supply chain platforms, ecosystems, B2B interactions, digital transformation, and business networks is essential in modern management, enhancing efficiency, transparency, and resilience. These elements address the complexities in global supply chains, including product demands, costs, prices, lead times, and quality [9]. Digital technologies, such as blockchain and IoT, facilitate decentralized trust mechanisms, improving transparency and real-time data verification, essential for managing interconnected supplier networks. This shift from centralized to decentralized models underscores digital technologies' potential to revolutionize supply chain dynamics [35].

Fragmented supply chains often lead to inefficiencies, waste, and potential fraud, undermining product quality and safety. Blockchain technology enhances traceability and transparency, particularly in food supply chains [18]. The proliferation of counterfeit goods necessitates reliable methods for product lifecycle tracing and authenticity verification, supported by blockchain platforms [33].

The lack of centralized and standardized data complicates risk identification, highlighting the need for collaborative platforms enhancing data transparency [10]. Technological advancements, like integrating UAVs and blockchain in inventory management, address inefficiencies and inaccuracies in traditional methods [36]. The scalability of algorithms remains a challenge, as they struggle to maintain performance with increasing data sizes, emphasizing the need for robust computational solutions [37].

Network science provides insights into the resilience of Supply Chain Networks (SCNs) by modeling interconnections between firms, enhancing risk management and robustness. However, blockchain networks are hindered by differing consensus protocols and governance structures, leading to data silos impeding interoperability and data sharing [38]. Addressing these challenges is crucial for fostering innovation and competitiveness within supply chains.

Limited visibility beyond tier-1 suppliers creates blind spots in risk management, emphasizing comprehensive visibility across tiers [39]. Current research categorizes based on attack sophistication, such as advanced attacks like Stuxnet versus simpler ones like Kaseya, alongside regulatory responses [7]. Leveraging digital transformation strategies enables organizations to navigate complexities, enhancing overall performance and resilience. Integrating these interconnected concepts fosters innovation, competitiveness, and sustainability in supply chain management.

3 Supply Chain Platforms and Digital Transformation

3.1 Technological Influences

Digital technologies are reshaping supply chain management, enhancing efficiency, transparency, and security. As illustrated in Figure 2, the key categories influencing this transformation include Blockchain Technology, Network Science, and Optimization and Integration. Each category encompasses specific applications and frameworks that contribute to these enhancements. For instance, blockchain's decentralized ledger significantly improves traceability and safety in food supply chains by securely tracking product movements and quality [18]. The Blockchain-based Agricultural Food Supply Chain Framework (BAFSCF) exemplifies this integration, merging blockchain and IoT to bolster transparency and trust [4]. In healthcare, blockchain frameworks employing smart contracts and decentralized storage optimize stakeholder interactions, enhancing security and efficiency [2]. IoT contributes to transparency through real-time data collection, though its adoption is limited

[10]. UAVs integrated with blockchain for inventory management demonstrate potential in resolving traditional system inefficiencies [36].

Network science aids supply chain management by modeling Supply Chain Networks (SCNs), improving risk management [11]. The Reconstructed Supply Network (RSN) method, using mobile phone communication data, transforms conventional supply chain management [8]. Advancements in forecasting methodologies, such as the EW GGM, enhance decision-making in collaborative networks. The SPOQchain platform highlights technology's role in lifecycle tracking while preserving user privacy [33]. Software connectors facilitate blockchain integration with enterprise systems, addressing trust and transparency [6]. A multi-objective optimization model balances cost minimization and timely delivery, showcasing digital technologies' optimization potential in supply chains [9].

Blockchain and digital twins illustrate digital frameworks' transformative potential in optimizing supply chain operations, enhancing data transparency and resource sharing while addressing information accessibility and asset traceability challenges. By leveraging these technologies, organizations can gain sustainable competitive advantages, improve decision-making, and foster continuous innovation, leading to more resilient logistics systems [40, 41].

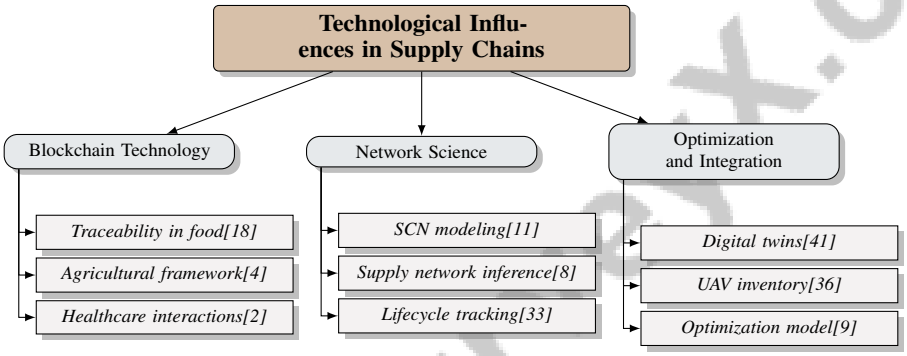

Figure 2: This figure illustrates the technological influences reshaping supply chain management, highlighting key categories such as Blockchain Technology, Network Science, and Optimization and Integration. Each category encompasses specific applications and frameworks that enhance efficiency, transparency, and security in supply chains.

3.2 Case Studies and Examples

Method Name	Technological Integration	Sector Applications	Performance Improvements
BSCF[2]	Blockchain And Iot	Healthcare Supply Chain	Improve Efficiency
BIoTP[26]	Blockchain Iot	Regulated Supply Chains	Process Validation Efficiency
BFS-CMS[18]	Blockchain Technology	Food Supply Chain	Enhance Efficiency, Transparency
IBT-ICT[42]	AI Technologies	Ict Supply Chains	Configuration Deployment Time
UAV-BIS[36]	Uavs And Blockchain	Industrial Settings	Data Collection Speed
BESS[6]	Blockchain Iot	Supply Chain	Data Sharing

Table 1: Overview of various digital technologies and their integration across different supply chain sectors, highlighting their impact on performance improvements. The table summarizes methods involving blockchain, IoT, AI, and UAVs, demonstrating enhanced efficiency, transparency, and data management capabilities in healthcare, food, industrial, and ICT supply chains.

Case studies across sectors demonstrate digital technologies' transformative power in supply chain management, improving efficiency, transparency, and competitiveness. Table 1 presents a comparative analysis of digital technologies integrated into supply chain management, illustrating their application and performance enhancements across multiple sectors. The TradeLens platform by Maersk and IBM revolutionizes global supply chains by enhancing data transparency and reducing shipping times through blockchain integration [35]. Similarly, the Walmart-IBM Food Trust initiative applies blockchain to improve food traceability, enhancing product safety and integrity [35]. In healthcare, blockchain-enabled platforms improve supply chain performance by connecting stakeholders via smart contracts, automating processes, and minimizing service times [2]. A platform tested during the 2020 IH season demonstrated superior performance in verification time and data integrity compared to traditional methods [26].

IoT and blockchain integration in logistics has been validated through simulation models illustrating blockchain's effectiveness in shipment tracking, improving data accessibility and transparency [43]. RFID technology alongside blockchain in food supply chains enhances traceability from farm to retail [18]. In network management, the Intent-Based Networking (IBN) approach, evaluated in a simulated ICT supply chain environment, shows significant improvements over traditional methods [42]. This underscores advanced digital strategies' role in optimizing supply chain operations.

Digital transformation's impact on inventory management is illustrated by an autonomous warehouse system that significantly improves inventory data collection speed compared to traditional methods [36]. Collaborative forecasting practices between HP and a microprocessor provider highlight enhanced data sharing benefits, improving decision-making speed and efficiency [34]. Experiments showing improved economic outcomes for companies engaging in information sharing further support blockchain's role in enhancing supply chain performance [6]. Collectively, these case studies underscore digital technologies' transformative potential in modernizing supply chain management, driving innovation, and fostering sustainable competitive advantages across industries.

3.3 Technological Frameworks for Supply Chain Optimization

Method Name	Technological Integration	Data Management	Operational Efficiency
TDTP[38]	Consensus Proofs	Trusted Data Exchange	Proof Validation
MLBA[44]	Blockchain Technology	Data Integrity	Parallel Processing
GNN-SCLP[45]	Graph Neural Networks	External Company Data	Predictive Analytics
BTS[46]	Hyperledger Fabric	Tamper-proof System	Real-time Tracking
MLSCM[47]	-	Decentralized Decision-making	Multi-agent System
KGMA[39]	Machine Learning Techniques	Decentralized Systems	Graph Analytics
SDM[48]	-	-	Linear Time Algorithm

Table 2: Overview of technological frameworks and their impact on supply chain optimization. The table details various methods, highlighting their integration of advanced technologies, approaches to data management, and contributions to operational efficiency. This comprehensive comparison underscores the transformative potential of these technologies in enhancing transparency, efficiency, and resilience in supply chain management.

Advanced technological frameworks, including blockchain, digital twins, AI, and IoT, are pivotal in optimizing supply chains by enhancing transparency, efficiency, and resilience. Blockchain's decentralized architecture is crucial for data integrity and eliminating single points of failure. The Trusted Data Transfer Protocol (TDTP) facilitates trusted data exchange between permissioned blockchain networks, improving interoperability and data sharing [38]. A multi-layered blockchain architecture enhances data sharing and management in drug supply chains while prioritizing patient privacy [44].

Digital twins leverage AI, machine learning, and IoT to create virtual models simulating real-world logistics and supply chain processes, improving operational efficiency and transparency. Integrating the Supply Chain Operations Reference (SCOR) model with the system of systems (SoS) theory establishes a standardized framework for constructing Supply Chain Digital Twins (SCDTs), enhancing reliability in supply chain management. Graph neural networks predict supplier-customer relationships, improving resilience by analyzing structural and external company data [45].

IoT technology enhances supply chain transparency through real-time data collection and verification. Blockchain application in food supply chains creates a tamper-proof system for tracking products from farm to fork [46]. The multi-agent approach in Multi-Layer Supply Chain Modeling (MLSCM) simulates the behavior and interactions of supply chain entities across different layers, providing insights into complex dynamics [47]. AI contributes to supply chain optimization, utilizing knowledge graph completion methods and graph analytics to enhance resilience [39]. A linear time algorithm computes unique equilibria in series-parallel networks, addressing complexity challenges faced by traditional methods [48].

Integrating these technological frameworks signifies a transformative shift in supply chain optimization, driving innovation, competitiveness, and sustainability in the digital age. By adopting advanced technologies such as blockchain, knowledge graphs, and collaborative platforms, organizations can substantially improve transparency, operational efficiency, and resilience. These enhancements facilitate compliance with regulatory and sustainability standards while enabling better risk management through comprehensive visibility across multi-tier supply chains. This strategic technological

adoption fosters collaboration among stakeholders, ultimately leading to sustainable competitive advantages in an increasingly complex global market [10, 31, 32, 49, 40].

As illustrated in Figure 3, the integration of advanced technological frameworks such as blockchain, AI, and IoT is crucial in optimizing supply chains. The figure highlights the role of blockchain in ensuring data integrity, the application of AI in enhancing digital twins, and the use of IoT for real-time data collection. Collectively, these technologies showcase their significant impact on transparency, efficiency, and resilience in supply chain management. The first diagram, "Vehicle Flow and Control System Diagram," captures the dynamics of vehicle traffic within a system, emphasizing the importance of managing vehicle flow to optimize supply chain operations. The second diagram, "Assembly Network," illustrates the intricate connections between components, underscoring the role of traceability and technology adoption in supply chain networks. Together, these examples underscore the critical role of digital transformation and technological frameworks in optimizing supply chains, ultimately leading to enhanced operational efficiency and effectiveness [50, 51]. Complementing these insights, Table 2 provides a comparative analysis of different technological frameworks employed in supply chain optimization, elucidating their respective technological integrations, data management strategies, and operational efficiencies.

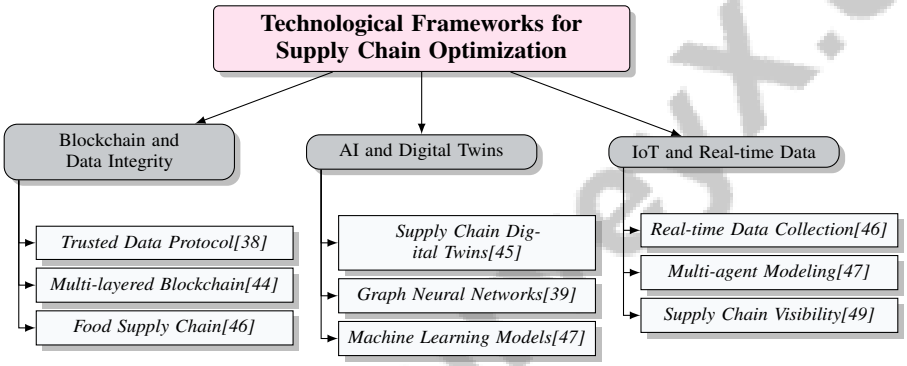

Figure 3: This figure illustrates the integration of advanced technological frameworks such as blockchain, AI, and IoT in optimizing supply chains. It highlights the role of blockchain in ensuring data integrity, the application of AI in enhancing digital twins, and the use of IoT for real-time data collection, showcasing their collective impact on transparency, efficiency, and resilience in supply chain management.

4 Ecosystems and Business Networks in B2B Supply Chains

4.1 Collaboration Models and Stakeholder Engagement

In B2B supply chains, collaboration models are pivotal for enhancing stakeholder engagement and operational efficiency. Blockchain technology plays a critical role by offering transparency and trust, enabling comprehensive tracking of product origins and transformations, which fosters collaboration among stakeholders [6]. In agricultural supply chains, blockchain frameworks facilitate traceability through decentralized systems, enhancing stakeholder cooperation [4].

Collaborative platforms are essential for advancing stakeholder engagement, allowing transparent data sharing and access among suppliers, thereby improving key performance metrics such as fill rates and profit margins [10]. Flexible systems that adapt to diverse production processes are crucial in the agri-food sector, accommodating varying needs and enhancing collaboration within supply chain ecosystems.

Strategic partnerships and collaboration models are increasingly vital in the AI supply chain ecosystem, driving innovation and stakeholder engagement. Information Technology (IT) is instrumental in facilitating collaboration among suppliers, manufacturers, and customers, enhancing data integration and supporting informed decision-making [6]. Decentralized collaboration protocols, such as the SAMP-SB protocol, exemplify market-driven interactions that boost engagement through competitive resource bidding.

Trust and collaboration are essential for mitigating financial risks in supply chains, particularly in agriculture. Blockchain-based systems enhance collaboration by providing verified information about product quality and origin, improving overall supply chain integrity [4]. These models and strategies illustrate the transformative potential of innovative frameworks in driving efficiency and stakeholder engagement within B2B supply chain ecosystems. By integrating advanced technologies and sustainable practices, a collaborative environment is fostered, crucial for maintaining competitiveness and resilience in the digital age.

4.2 Challenges in Ecosystem Development

Developing and maintaining business networks within supply chain ecosystems face challenges, primarily concerning trust management, security vulnerabilities, and technological complexities. Ineffective trust management, particularly during product lot splitting and merging, often leads to inefficiencies and disruptions [52].

Security vulnerabilities, especially with the rise of supply chain attacks, present significant challenges. These often stem from component reuse, risking entire ecosystems like the Ethereum network, highlighting the need for robust security protocols [53].

Blockchain application development in supply chains is hindered by a steep learning curve for developers and challenges in reusing existing code, which can impede collaboration and innovation [54]. While blockchain enhances verification processes and reliability, increased processor consumption during certain transactions necessitates optimization for efficient operations [44].

Despite these challenges, blockchain technology offers significant advantages, including improved reliability and adaptability for applications beyond food traceability. Addressing inherent challenges, such as optimizing resource consumption and enhancing developer capabilities, is crucial for leveraging these benefits [55].

Challenges faced by supply chain ecosystems—including the need for enhanced scalability, integration of decision-making across different time horizons, and the orchestration of human and machine intelligence—highlight the demand for innovative solutions and strategic frameworks. These frameworks should enhance trust management and security, particularly regarding blockchain technology and smart contracts, while fostering stakeholder collaboration. As businesses transition from traditional competitive models to collaborative, technology-enabled networks, addressing these challenges is essential for maintaining efficiency and meeting the dynamic demands of customers and stakeholders [14, 31, 13].

5 Impact on Supply Chain Management

The integration of advanced technologies has become essential in supply chain management, enhancing operational efficiency and strategic responsiveness. This shift is driven by the need for improved collaboration and real-time information exchange among stakeholders, optimizing processes and transforming procurement from cost-centric to value-generating collaborations. Traceability solutions are crucial for tracking product information, improving decision-making and stakeholder cooperation, enabling organizations to better navigate market disruptions and secure sustainable competitive advantages [31, 56, 32, 28]. Understanding competitiveness and agility dynamics is vital for maintaining a competitive edge, as digital platforms, particularly blockchain and IoT technologies, reshape supply chain strategies and practices.

5.1 Competitiveness and Agility through Integration

Digital platforms, especially blockchain and IoT technologies, are central to enhancing competitiveness and agility in supply chain management by optimizing operations, improving data transparency, and facilitating strategic decision-making. Blockchain enhances traceability and operational efficiency, providing a secure system for tracking product movements and quality assessments, notably in food supply chains [46, 4]. The SPOQchain platform exemplifies improved efficiency, security, and privacy in supply chain tracing, fostering competitiveness [33]. The Trusted Data Transfer Protocol (TDTP) further enhances competitiveness by enabling secure data sharing among independent blockchain networks, reducing data management fragmentation [38].

IoT integration enhances security through accurate threat mapping and comprehensive risk assessments, crucial for agile supply chain operations. Utilizing mobile phone data improves systemic risk understanding, enhancing competitiveness and agility [8]. Advanced network models, such as those proposed by [9], illustrate trade-offs between costs and delivery delays, offering decision-makers options to boost efficiency.

Collaborative forecasting approaches visualize and analyze complex interactions, leading to better decision-making and accuracy [34]. Dynamic methods adjust to uncertainties, enabling SMEs to navigate market fluctuations and maintain sustainability and competitiveness [1]. Recognizing the role of human and machine intelligence in effective management highlights the importance of multi-agent systems in decision-making [13].

Despite digital advancements, legal measures are insufficient to mitigate supply chain attacks, indicating a need for stricter regulations and accountability mechanisms [7]. These digital frameworks signify a transformative shift in supply chain management, driving innovation, efficiency, and resilience, fostering sustainable competitive advantages in the digital age.

5.2 Resilience and Risk Management

Building resilient supply chains and managing risks are imperative in today's complex digital landscape. Blockchain technology offers a decentralized, secure, and tamper-proof solution, enhancing traceability and bolstering overall resilience [57]. This is crucial in cold supply chains, where overcoming data integration, technological infrastructure, and security concerns is essential for IoT technologies' success [58].

Implementing scalable, multi-layered blockchain architectures introduces parallelism, improving scalability and transaction throughput, addressing traditional methods' limitations, and enhancing risk management and operational efficiency [44]. Dynamic, self-adapting systems for predictive cyber risk analytics are crucial for SMEs, aligning supply chain strategies with evolving IIoT technologies and mitigating cyber risks [59].

Social Network Analysis (SNA) is a valuable framework for identifying critical facilities within Closed-Loop Supply Chain (CLSC) networks, providing insights into performance and risk management. Leveraging SNA helps organizations identify vulnerabilities and optimize supply chain configurations to enhance resilience and mitigate risks [60]. These strategies underscore the importance of integrating advanced technological frameworks and analytical tools to build resilient supply chains capable of withstanding disruptions and adapting to dynamic digital demands.

In recent years, the complexities of digital supply chains have prompted researchers to explore various challenges and future directions that could enhance operational efficiency and resilience. To illustrate this multifaceted landscape, Figure 5 depicts a hierarchical structure that categorizes key issues and proposed solutions. This figure illustrates the hierarchical categorization of strategies and technologies enhancing resilience and risk management in supply chains, focusing on blockchain solutions, IoT and cyber risks, and network analysis. By visualizing these relationships, the figure underscores the importance of addressing these challenges in a cohesive manner to improve overall supply chain performance.

6 Challenges and Future Directions

6.1 Data Management and Security

Ensuring data integrity, privacy, and operational efficiency in digital supply chains presents significant challenges. Blockchain technology enhances security and transparency by decentralizing data, reducing reliance on intermediaries [2]. However, its decentralized nature can lead to scalability issues, necessitating substantial computational resources and complicating data management [61]. The integration of external storage systems, as seen with platforms like SPOQchain, highlights concerns regarding data management and access control, underscoring the need for secure infrastructure integration [33].

The transition of sectors like healthcare to digital platforms exposes the limitations of traditional systems in addressing data security, privacy, and scalability [44]. The lack of standardized protocols

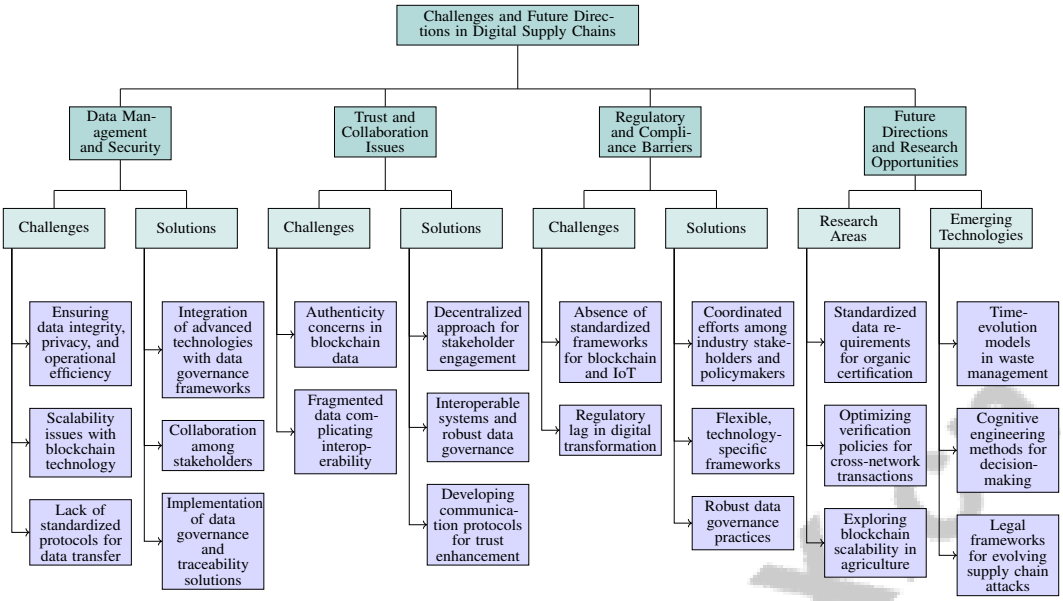

Figure 4: This figure illustrates the hierarchical structure of challenges and future directions in digital supply chains, categorizing key issues and proposed solutions across data management, trust and collaboration, regulatory barriers, and research opportunities, highlighting the interconnectedness of these elements in enhancing supply chain efficiency and resilience.

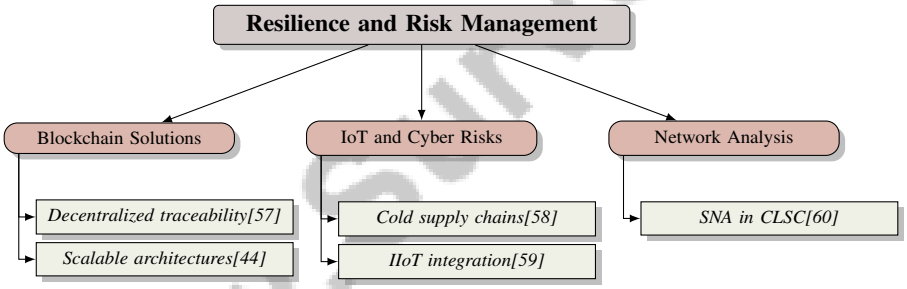

Figure 5: This figure illustrates the hierarchical categorization of strategies and technologies enhancing resilience and risk management in supply chains, focusing on blockchain solutions, IoT and cyber risks, and network analysis.

for data transfer among Distributed Ledger Technology (DLT) implementations complicates data management, necessitating interoperable solutions [38].

Current national regulations often lack specificity regarding technology, posing challenges in enforcing data security measures [7]. Addressing these challenges requires integrating advanced technologies with robust data governance frameworks to enhance data quality, mitigate silo risks, and ensure regulatory compliance. Collaboration among stakeholders and the implementation of effective data governance and traceability solutions can bolster the resilience and efficiency of digital supply chains, facilitating data-driven decision-making while incorporating sustainability considerations [62, 63, 32].

6.2 Trust and Collaboration Issues

Trust and collaboration remain pivotal yet challenging in supply chain management amid digital transformation. Concerns about the authenticity of data on blockchain systems can undermine trust in data integrity and product quality [64]. Fragmented data, particularly in healthcare, complicates interoperability and collaborative efforts among stakeholders [44].

Decentralized systems in e-commerce and supply chains introduce scalability and infrastructure complexity challenges, hindering technology integration [65]. Ensuring stakeholder participation and trust in sharing sensitive data is crucial, especially in competitive environments [22].

In agricultural food supply chains, trust and collaboration issues necessitate a decentralized approach to enhance stakeholder engagement and transparency [4]. Interoperability challenges and regulatory compliance issues can limit decentralized frameworks' efficacy [46]. A comprehensive strategy addressing trust and collaboration challenges in blockchain networks should include interoperable systems, robust data governance, and regulatory compliance adherence. Developing communication protocols that enhance trust through consensus mechanisms will facilitate secure data sharing across blockchain networks. Additionally, fostering interdisciplinary skills in blockchain technology through education and industry collaboration will support successful integration and adoption across sectors [38, 27]. By cultivating transparency and mutual trust, stakeholders can improve collaboration, data integrity, and supply chain efficiency and resilience.

6.3 Regulatory and Compliance Barriers

Regulatory challenges and compliance barriers significantly shape digital supply chain transformation. The absence of standardized frameworks for technologies like blockchain and IoT leads to implementation inconsistencies across jurisdictions [7]. This lack of standardization complicates interoperable system development and seamless cross-border data exchange, creating compliance risks for organizations operating in multiple regions.

Existing data privacy regulations often fail to address decentralized systems' unique security and privacy concerns, resulting in data management vulnerabilities [38]. This regulatory gap necessitates robust data governance policies for compliance with diverse standards.

The complexity of supply chain networks exacerbates compliance challenges, as stakeholders must adhere to various regulatory requirements. This is particularly pronounced in healthcare, where stringent compliance standards ensure product safety [44]. The rapid pace of digital transformation often outpaces regulatory bodies' ability to update and enforce standards, leading to a regulatory lag that can stifle innovation and competitiveness.

Addressing these barriers requires coordinated efforts among industry stakeholders, policymakers, and regulatory bodies to establish flexible, technology-specific frameworks accommodating swift digital transformation. Collaboration among diverse stakeholders and clear guidelines can help organizations navigate the complex regulatory landscape, ensuring compliance and enhancing digital technology utilization for tracking product information and mitigating operational risks. Implementing robust data governance practices enables organizations to leverage data-driven insights for optimizing operations, achieving strategic goals, and maintaining market competitiveness [10, 62, 32, 28].

6.4 Future Directions and Research Opportunities

The digital transformation of supply chains offers numerous research opportunities, particularly in optimizing emerging technology integration. Developing standardized data requirements for organic certification and improving interoperability among blockchain platforms can enhance transparency and traceability in agricultural supply chains [46]. Optimizing verification policies and extending the Trusted Data Transfer Protocol (TDTP) for cross-network transactions can significantly bolster data integrity and security across decentralized systems [38].

In transportation logistics, research should explore alternative models and outsourcing implications to optimize costs and enhance efficiency [9]. Applying time-evolution models in sectors like waste management and biorefinery could validate their robustness and adaptability, providing valuable insights into dynamic supply chain management [1].

The agricultural sector offers further research opportunities, particularly in optimizing blockchain scalability and exploring additional use cases to drive innovation and sustainability [4]. Developing legal frameworks that adapt to evolving supply chain attacks, including integrating digital service providers into critical infrastructure definitions, is crucial for enhancing security and resilience [7].

Advancing cognitive engineering methods that consider human input and designing systems that facilitate coordination among decision-makers is essential for improving supply chain management

[13]. Addressing these challenges and opportunities can pave the way for more resilient, efficient, and sustainable supply chain ecosystems, fostering innovation and competitiveness in the digital age.

7 Conclusion

This survey delves into the transformative effects of advanced digital technologies on supply chain management, particularly through the deployment of supply chain platforms, ecosystems, and B2B digital transformation. Technologies such as blockchain and IoT significantly enhance transparency, efficiency, and security by enabling decentralized trust mechanisms, improving traceability, and optimizing operations. These capabilities are crucial for fostering competitiveness and resilience in today's digital landscape.

The focus on ecosystems and business networks highlights the importance of collaboration and stakeholder engagement in leveraging collective capabilities to drive innovation. Collaborative platforms play a pivotal role in enhancing data transparency and trust among supply chain participants, which in turn improves performance metrics and informs strategic decision-making. These findings underscore the need for robust frameworks and strategic partnerships to navigate the complexities and uncertainties inherent in global supply chains.

Practically, organizations are encouraged to prioritize the integration of digital technologies to enhance supply chain visibility and resilience. The development of interoperable systems and standardized protocols is vital for seamless data exchange and compliance with regulatory standards. Addressing challenges related to data management, trust, and regulatory compliance is essential for optimizing supply chain operations and achieving sustainable competitive advantages.

Future research should explore advanced modeling techniques for supply chain optimization, scalable blockchain solutions, and the integration of AI and digital twins in supply chain management. Investigating the implications of emerging technologies across sectors such as agriculture and healthcare will provide valuable insights into enhancing supply chain dynamics and fostering innovation. By pursuing these research avenues, the field can advance towards more resilient, efficient, and sustainable supply chain ecosystems.

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