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Review Article

Unraveling the potential of blockchain technology in enhancing supply chain traceability: A systematic literature review and modeling with ISM

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ABSTRACT

Supply chain traceability is a critical aspect of modern business operations, and blockchain technology has emerged as a promising solution to enhance traceability in supply chain management. However, the effective application of blockchain faces various challenges and limitations. This study aims to investigate how blockchain technology can address these challenges and improve traceability within supply chains. Employing a systematic literature review combined with interpretative structural modeling (ISM), we comprehensively assess and classify the literature on blockchain-enabled supply chain traceability. Our exploratory research approach delves into the contributions of blockchain technology and identifies key factors that enhance traceability. We adopt a mixed-methods approach, incorporating both secondary and primary data to ensure robust analysis. Our study addresses essential questions regarding the application, advantages, limitations, challenges, integration with other technologies, and future potential of blockchain in supply chain traceability. Through a systematic review and the ISM technique, we identify crucial levels and factors necessary for leveraging blockchain technology effectively. Our findings underscore the importance of a robust infrastructure, cutting-edge technology, and significant initial investment in implementing blockchain for supply chain traceability. This research offers a comprehensive understanding of the factors and their levels, providing valuable insights for industry professionals and academic researchers. By laying a solid foundation for informed decision-making and further exploration into the potential of blockchain-enhanced supply chain traceability, our study contributes to advancing knowledge in this crucial area of business operations.

1. Introduction

Supply chain transparency remains a pivotal challenge for governments and enterprises. It is not just about compliance with regulations or the optimization of operational efficiencies; it is about ensuring product quality and fostering sustainable practices. At the heart of this challenge is the concept of traceability, which encompasses the ability to trace a product's journey throughout the supply chain—from the source to the end consumer [1–3]. A potential solution to address this complexity is blockchain technology, as highlighted by Guo et al. [4].

The introduction of blockchain by Nakamoto in 2008 was initially geared towards financial transactions and distributed ledger systems. Its success in the cryptocurrency area highlighted its versatility, with applications extending to various industries, including drugs, food, agriculture, etc. [5]. Its foray into supply chain management (SCM) underscored its strengths, such as smart contracts and enhanced visibility, transforming traditional supply chain processes [6].

The evolution of blockchain within supply chains represents a journey from nascent exploratory applications to a cornerstone for enhancing transparency, efficiency, and trust. Notably, its initial applications focused on high-value goods such as diamonds to combat fraud and enhance traceability [7]. Over time, its utility has expanded across sectors, including agriculture for provenance and pharmaceuticals for securing drug supply chains [5,8]. Today, the trend is towards integrating blockchain with the Internet of Things (IoT) and artificial intelligence (AI) to create smarter, more resilient supply chains [9],

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signaling a shift towards comprehensive digital transformations.

Blockchain technology seeks to address several pervasive challenges in supply chain traceability. These include overcoming the opacity in global supply chains, ensuring the authenticity of goods, and facilitating swift responses to recalls and quality control issues. For example, in the food sector, blockchain has been instrumental in tracing the journey of production from farm to table, addressing consumer demands for transparency and food safety [10]. Similarly, in the pharmaceutical industry, it helps combat counterfeit drugs by providing a secure and immutable record of each transaction within the supply chain [11].

However, merging blockchain with supply chain traceability is not without its set of challenges. While the technology promises enhanced data sharing, real-time data collection, and advanced quality control, issues related to scalability and transaction latency remain. This gives rise to a pertinent question: do the advantages outweigh the challenges? The existing literature, including studies by Zhang et al. [12], Azevedo et al. [13], and others, has often taken an industry-specific approach, underscoring the need for a broader perspective.

This research endeavors to fill the identified gaps, aiming to provide a comprehensive view by combining a systematic literature review (SLR) and employing interpretative structural modeling (ISM). Significant works, such as those by Biswas et al. [14], Dietrich et al. [15], Pournader et al. [11], and Wang et al. [16], have highlighted the transformative impacts of blockchain on supply chain practices, particularly in the realms of traceability, digitization, and security. Conversely, insights from Amentae et al. [17] and Mahyuni et al. [18] emphasize the benefits of digitizing supply chains with blockchain, particularly in the food industry.

Foundational research articles, such as those by Saberi et al. [10] and Ivanov et al. [19], reiterate the significance of traceability within the SCM landscape. In this context, our study is dedicated to a systematic review of the literature concerning supply chain traceability within the blockchain paradigm. Driven by the gaps identified, our methodology adheres to the "preferred reporting items for systematic reviews and meta-analyses" (PRISMA) checklist and the ISM approach. We aim not only to explore blockchain applications in SCM but also to amalgamate insights from diverse research sources.

To guide our exploration and provide structure for our comprehensive review, we frame the following research questions:

- **RQ1**: What are the main applications of supply chain traceability and blockchain technology (STBB) discussed in the scientific literature?
- **RQ2**: What are the benefits and advantages of STBB discussed in the scientific literature?
- **RQ3**: What are the limitations and challenges of STBB discussed in the scientific literature?
- **RQ4**: What does the future of STBB look like, and how can STBB integrate with other technologies, as discussed in the scientific literature?
- **RQ5**: How is the modeling of STBB discussed in the scientific literature?
- **RQ6**: What are the relationships among supply chain traceability components in the context of blockchain?

RQ1 focuses on STBB applications, considering specific industries and managerial perspectives. The scientific literature highlights a wide range of applications for STBB across industries such as the diamond trade, luxury goods, food, e-commerce, agriculture, pharmaceuticals, sustainability, healthcare, automobile, insurance, logistics, and mineral tracking. These applications address challenges related to transparency, fraud prevention, origin tracking, safety, supply chain monitoring, authentication, and serialization. RQ2 addresses the benefits of STBB compared to traditional methods, highlighting workforce, time, and cost savings; the benefits from distributed ledgers, smart contract usage; and the promotion of sustainable products. STBB offers enhanced trust, transparency, and security within supply chains. It ensures data integrity, compliance with regulations, and privacy protection through encryption techniques. STBB also facilitates knowledge sharing, efficiency, and reliability, with authorized blockchains providing a secure platform for traceability. RQ3 addresses the limitations and challenges of STBB. The limitations and challenges of STBB include issues such as immature technology, managing large transaction volumes, technology acceptance and interoperability, infrastructure and investment requirements, complexity of use, conflicts among supply chain stakeholders, data privacy concerns, supply chain security and trust issues, immutability of records, time latency in transactions, and scalability of blockchain solutions. Addressing these challenges is essential for the successful implementation and adoption of STBB in various industries. RQ4 explores the integration of blockchain with other technologies, such as the IoT, radio frequency identification (RFID), and Industry 4.0, as an emerging trend. This study explores the potential advancements and impacts of combining blockchain with the IoT, RFID, and smart contracts in SCM. This analysis aims to uncover opportunities for enhancing traceability, transparency, and sustainability in supply chains through the integration of blockchain technology with other innovative solutions. RQ5 examines STBB as a subsystem, supersystem, or component within the overall system. The analysis of the reviewed models indicates that tracking is often viewed as a subsystem, with a focus on its primary role and output. Blockchain is typically positioned as a supportive subsystem, enhancing tracking capabilities. The existing literature on the modeling of STBB explores its role as a subsystem within the supply chain ecosystem, emphasizing the importance of integrating blockchain as a component for enhanced traceability and transparency. Studies highlight the need for robust modeling frameworks to optimize supply chain processes and improve overall efficiency. The supply chain is recognized as the main application area for blockchain-based tracking. This classification provides insights into the roles and relationships of tracking, blockchain, and the supply chain within modeling efforts, contributing to future research and development in this field. Finally, RQ6 visually represents the relationships among the components, with findings indicating that the components at the fourth level, or the final level, exhibit the strongest connections and impact on other dimensions. The components of supply chain traceability within the blockchain context show strong interdependencies, with the fourth-level components having the most significant impact on the overall system. Understanding these relationships is crucial for enhancing supply chain efficiency and effectiveness through informed decision-making and strategic optimization.

This study makes a significant contribution to the existing literature by providing a comprehensive analysis of STBB across various industries. By examining the applications, benefits, limitations, and challenges of STBB, we offer valuable insights into the potential impact of blockchain technology on SCM. Our exploration of diverse industry sectors where STBB has been implemented, alongside a discussion of the advantages and drawbacks of this technology, aims to enhance understanding and inform decision-making in the adoption of blockchain for supply chain traceability. Additionally, our examination of the integration of blockchain with other technologies, such as the IoT and RFID, provides insights into the evolving landscape of SCM. Through this analysis, we contribute to the advancement of knowledge in the field of STBB and pave the way for future research and practical implementations in supply chain traceability.

This article systematically investigates the impact of blockchain technology on enhancing supply chain traceability, combining a literature review and ISM to understand key factors and their relationships. Section 2 describes our methodology, detailing the selection process for relevant literature and setting the stage for a comprehensive analysis. In Section 3, we present our findings, highlighting trends and gaps from the literature review and insights from the ISM analysis on the variables' hierarchical interdependencies. Section 4 discusses these findings, comparing them with existing research to draw conclusions on blockchain's potential and challenges in supply chains, and outlines a future research agenda. Section 5 proposes a structured framework that caters to both quantitative and qualitative explorations in the domain of STBB. In Section 6, we present the conclusions.

This article aims to enrich the knowledge based on supply chain traceability and blockchain, paving the way for future research and practical implementation in this vital area.

2. Research methodology

This article takes a two-pronged approach to studying the subject matter. First, a systematic review is conducted to identify the relevant components. The existing literature is carefully analyzed to determine these components. The ISM method is then used to categorize and understand the relationships among these components within the context of blockchain in the supply chain. The use of ISM as an approach is valuable in modeling and analyzing the complex interrelationships among the different indicators in the supply chain field.

This literature review adheres to the methodological framework outlined by the PRISMA checklist. The inclusion and exclusion criteria have been clearly articulated in this section, ensuring that relevant research papers within our designated research area are identified and included in the study. By following the PRISMA guidelines, this review aims to maintain transparency and rigor in the selection process of research documents, enhancing the quality and reliability of the findings.

A total of 155 articles were systematically filtered, and their abstracts and full texts were reviewed to determine their alignment with the research questions. From this initial screening, 90 articles were deemed relevant and selected for the final review. Throughout the process, key bibliographic details such as publication year, source, country, article type, and citations were recorded. The review was conducted meticulously, following established procedures, and the following three subsections provided comprehensive information on the search strategies, data sources, inclusion criteria, and exclusion criteria, as well as the overall search results. These details ensure transparency and allow readers to assess the study's thoroughness and reliability.

2.1. Search strategies and data sources

The Scopus database was selected as the primary source for this study, given its extensive coverage of peer-reviewed journals. The search process was conducted in two stages. In the first stage, referenced review articles were carefully selected and examined to align with the research aim and questions. In the second stage, all the articles containing the targeted keywords were searched within the Scopus database until January 23, 2022.

Given the focus on STBB, the search strategy simultaneously considers three key areas: the supply chain, traceability, and blockchain. Two searches were performed using keywords with various spellings and semantically related concepts. For example, for blockchain, both continuous and discontinuous variations were considered; and for the supply chain, the same approach was followed. Additionally, terms related to tracking and traceability (such as traceability, tracing, tracking, and tracing) and transparency (including detection and transparency) were included. Duplicate articles were eliminated by conducting searches based on titles, authors, and abstracts, resulting in a refined set of articles for further screening and analysis.

2.2. Inclusion and exclusion criteria

The article screening process and identification of relevant works followed a two-step approach, guided by five inclusion and exclusion criteria. In the first step, performed by the system, three criteria were defined as follows: (1) articles must be scientific or review papers; (2) articles must be written in English; and (3) articles must be published in journals. In the second step, three reviewers assessed the remaining articles by downloading and reading the abstracts or full texts, applying two additional criteria: (4) the full texts of the identified articles must be accessible for further analysis and (5) the articles must discuss supply chain traceability based on blockchain technology. Furthermore, four sub-criteria were established for the last criterion: (a) the article's main topic should be blockchain and address supply chain traceability; (b) the article's main topic should be the supply chain and address blockchain-based traceability; (c) the article's main topic should be supply chain traceability and address blockchain; or (d) the article must provide insights that answer at least one of the five main research questions.

2.3. Search results

The article selection process was conducted in two rounds to ensure relevance and focus on the management field within the context of STBB. Initially, the initial list of 155 articles was examined to eliminate papers from unrelated areas such as engineering, environmental sciences, and ecology, resulting in 143 retained papers. In the second round, the titles, abstracts, and central parts of these 143 articles were thoroughly reviewed, further refining the selection by excluding articles that did not squarely fall within the cross-fields of STBB. This step led to the identification of 50 irrelevant research articles, and an additional three articles were excluded because their full texts were unavailable. A total of 90 articles were selected for a comprehensive review. The review process, depicted in Fig. 1, is illustrated to provide a visual representation of the selection process.

Next, the content of the selected research articles was meticulously analyzed, focusing on identifying key questions and extracting the main conclusions. Four authors independently categorized the key results and findings into various themes. The authors subsequently engaged in discussions to refine these themes and classifications, synthesize the conclusions, summarize the papers, and generate the outcomes of the literature review. This collaborative approach ensured a comprehensive analysis and interpretation of the research articles.

2.4. Interpretive structural modeling

This study employs the ISM method to investigate the intricate internal relationships among variables. After meticulous identification and listing of indicators, the ISM technique is aptly utilized to analyze the cascading effects of one variable on others. Its effectiveness lies in its ability to transform complex relationships into a comprehensible framework [20]. The ISM approach serves as a powerful tool for holistically constructing a network of relationships and interactions between dimensions. By employing ISM, the fundamental indicators relevant to the research topic are initially identified and subsequently interconnected. Through a hierarchical breakdown of indicators, the ISM approach facilitates an in-depth evaluation of the interrelationships, enabling a comprehensive examination of the multifaceted variables pertaining to the research problem [21,22]. Notably, the ISM design serves as an invaluable technique for assessing the dynamic impact of each variable on others. It offers a pervasive architectural framework that effectively constructs a model that captures the intricate relationships between variables. By employing this method, the vague and ambiguous mental models of complex systems are transformed into transparent and practical models, fulfilling a wide array of purposes within the research context [21].

The decision to utilize ISM stems from its capability to model and analyze complex interrelationships among numerous factors within a system. Given the intricate nature of supply chain traceability with blockchain technology, which involves numerous variables interacting in dynamic ways, ISM offers a structured approach to understanding these relationships. By employing ISM, we aimed to systematically unravel the dependencies and interactions among key factors influencing supply chain traceability in the context of blockchain. The hierarchical analysis framework of ISM allows us to categorize factors based on their

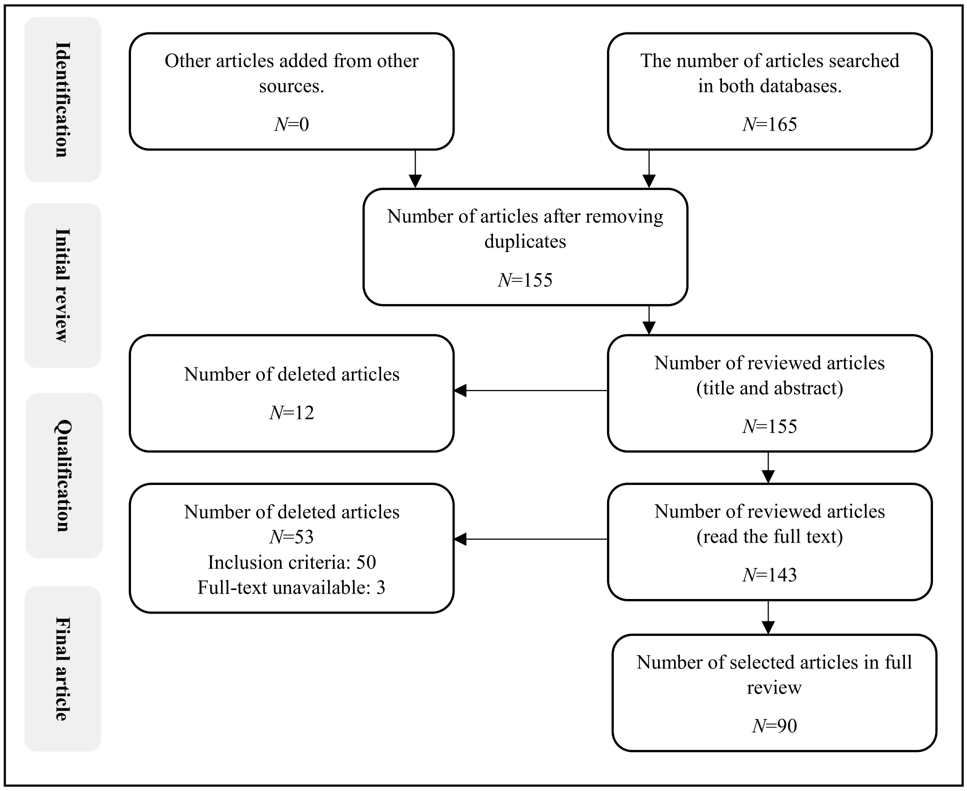

Fig. 1. Systematic literature review process (adapted from the PRISMA statement).

levels of influence and dependence, thereby providing a structured representation of the system's dynamics. In the realm of blockchain and supply chain traceability, where different layers of technology, stakeholders, and processes interact, ISM offers a methodical approach to delineate these complexities. By identifying critical factors and their interdependencies, ISM enables us to gain strategic insights into the implications of adopting blockchain technology for enhancing supply chain traceability. The ability of ISM to uncover hierarchical relationships and dependencies among various components of a supply chain traceability system aligns closely with our research objectives. Through comprehensive modeling of the supply chain traceability ecosystem and incorporating blockchain technology as a pivotal component, ISM enhances our understanding of the intricate dynamics at play and guides informed decision-making.

In the context of blockchain and supply chain traceability, ISM provides a structured framework for identifying key factors, variables, and their relationships within the system. By using ISM, researchers can map out the hierarchy of variables, determine the driving forces, and comprehend how various components interact with each other. This approach enables a systematic analysis of the factors influencing the implementation and effectiveness of blockchain technology in supply chain traceability. Moreover, ISM facilitates the identification of critical variables that significantly affect the overall performance of the supply chain traceability system. By employing ISM, researchers can uncover hidden relationships, dependencies, and feedback loops that may not be readily apparent through traditional analysis methods. The choice of ISM as the analytical tool in this study was based on its capability to manage complexity, capture interrelationships between variables, and provide a structured framework for understanding the dynamics of blockchain technology in supply chain traceability.

The study employs ISM to establish pairwise linkages between the factors under investigation. After confirming the indicators, the experts apply conceptual relationships to form eighteen components. The final accessibility matrix is subsequently derived, allowing for the determination of component levels and facilitating the classification and interactive network of factors. This is achieved by converting the symbolic relationships from the SSIM matrix into numerical values of zero and one in the accessibility matrix.

To implement the ISM approach and determine the sequence of relationship importance between problem elements, seven essential steps are followed:

1. Identification of variables relevant to the problem at hand.
2. Formation of a self-interaction structural matrix, which captures the relationships among the variables.
3. Creation of a primary accessibility matrix, which represents the initial relationships among the variables.
4. Generation of a final accessibility matrix, obtained by refining the relationships among the variables based on expert insights.
5. Segmentation of the levels, categorizing the components based on their importance and influence.
6. Development of the initial and final interpretive structural models, which visually depict the relationships among the components.

By following these steps, this study effectively applies the ISM approach to analyze the interconnections between problem elements and establish a clear hierarchy of importance and influence within the studied context.

3. Results

3.1. Review results

Prior to analyzing the research findings, we conducted a comprehensive review of the selected 90 articles. This review focused on essential details such as the journals they were published in, publication dates, author affiliations, research designs, and research contexts.

3.1.1. The number of research articles by journal

The selected 90 articles were sourced from a total of 50 journals. Among these journals, 13 stood out because they published more than two articles on the topic. The distribution of articles across 50 journals, with a notable concentration in *Sustainability*, the *Journal of Cleaner Production*, and the *International Journal of Production Economics*, underscores a multidisciplinary interest in blockchain applications for sustainable supply chain practices. The prominence of sustainability-focused journals suggests that future research could benefit from exploring the synergies between blockchain technology and sustainable supply chain initiatives, potentially leading to more effective and holistic approaches to environmental stewardship in SCM (see Table 1).

3.1.2. Distribution of the research articles across time periods

The temporal analysis reveals a significant increase in publications from 2018 to 2022, with the most dramatic increase observed after 2020. This surge likely reflects the accelerated digital transformation initiatives prompted by the COVID-19 pandemic, highlighting the potential of blockchain to increase resilience and efficiency in supply chains during times of disruption. The growing academic output in this period may also indicate evolving research areas within blockchain technology, such as the development of new frameworks for integration with existing supply chain operations and the exploration of blockchain's role in mitigating pandemic-induced supply chain vulnerabilities (see Fig. 2).

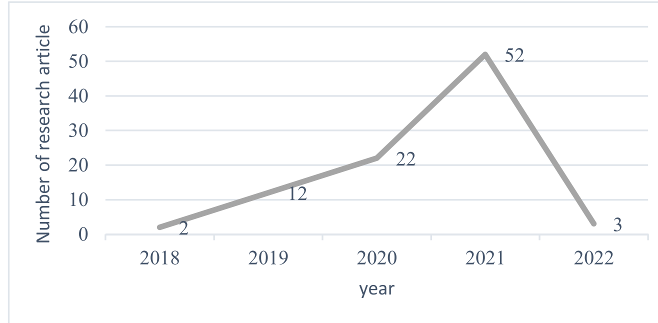

Fig. 2. The distribution of the research articles across time.

3.1.3. Distribution of the research articles by countries

The geographical analysis showing China, India, the United Kingdom, the United States, and Italy as leading contributors to blockchain research in supply chains reveals a global acknowledgment of blockchain's transformative potential. However, the dominance of China and India might reflect these countries' rapid technological advancements and substantial investment in blockchain technology. This distribution suggests a need for further exploration of how different regional policies, technological readiness, and supply chain dynamics influence blockchain adoption and implementation strategies. Moreover, the varied geographical contributions could encourage cross-border research collaborations, fostering a more diverse and comprehensive understanding of blockchain applications worldwide (see Fig. 3).

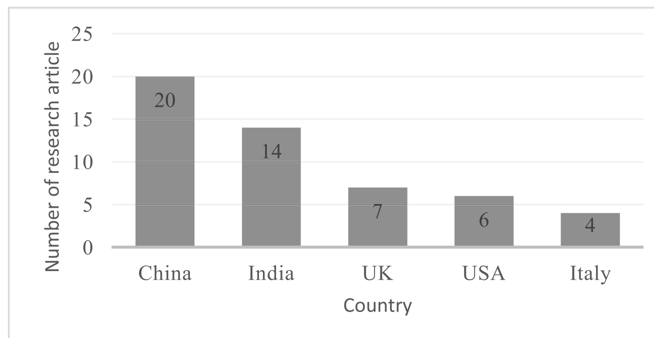

Fig. 3. The distribution of the research articles by countries.

3.1.4. Implications for future research

This in-depth analysis of the 90 articles not only addresses the reviewers' feedback by providing a richer understanding of the current state of blockchain research in supply chains but also identifies key areas for future investigations. This highlights the importance of interdisciplinary approaches to studying blockchain in supply chains, the influence of global events on research trends, and the need for international collaboration to harness blockchain's full potential. Future studies could focus on comparative analyses of blockchain adoption across different regions, the impact of regulatory environments on technology implementation, and the exploration of blockchain integration with other emerging technologies to address supply chain sustainability challenges more effectively.

Table 1
Number of research articles by journal.

Journal	H-Index	No. doc
Sustainability	109	20
Journal of Cleaner Production	232	4
International Journal of Production Economics	197	
International Journal of Production Research	153	3
International Journal of Information Management	132	
IEEE Engineering Management Review	27	
Production Planning and Control	85	
Journal of Enterprise Information Management	67	
International Journal of Physical Distribution and Logistics Management	117	2
IEEE Transactions on Computational Social Systems	33	
Foods	53	
Operations Management Research	31	
IEEE Transactions on Engineering Management	97	

3.2. Interpretive structural modeling results

3.2.1. Identification of variables related to the problem

This research uses experts' perspectives to examine the internal relationships among the main criteria. Through a systematic review, the components were identified and specified. Subsequently, consultations with academic and industrial experts were conducted to validate the indicators. The ISM technique was then employed to determine the internal relationships between the variables and prioritize them accordingly. This step involves calculating the super-pattern matrix, which captures the causal relationships between the main criteria and reveals the degree of influence and effectiveness of the variables. The resulting matrix, known as the internal communication matrix, provides valuable insights into the causal relationships between the factors.

Overall, this research combines expert perspectives, systematic reviews, and ISM to analyze the internal relationships among the main criteria comprehensively. By utilizing these approaches, the study gains a deeper understanding of the interconnections among variables and unveils their respective levels of influence and effectiveness, as depicted in the internal communication matrix.

3.2.2. Formation of the self-interaction structural matrix

In the subsequent step of ISM, the internal relationships between the indicators are calculated. This is accomplished by constructing a self-interaction structural matrix based on discussions and opinions from an expert group. The matrix is formed via four modes of conceptual relationships, considering the dimensions and indicators of the study and their comparison. The resulting matrix represents the experts' perspectives on the relationships among the components and serves as a reliable input for the ISM technique.

In this step, 10 experts evaluated the mutual relationships among the components. The experts determined the relationships by comparing the 18 components and providing insights into whether one factor directly affects another. The collective opinions and the resulting mutual relationships among the 18 components are presented in Table A.2 in the Appendix. This matrix illustrates which variables influence one another and which variables are influenced by others. The symbols used in the table denote the pattern of relationships among the elements, with "1" indicating that variable *i* affects variable *j*, "−1" indicating that variable *j* affects variable *i*, "2" indicating a two-way relationship, and "0" indicating the absence of a relationship (all the ISM tables are in the Appendix).

By incorporating the experts' opinions and representing the relationships between variables in the matrix, this step lays the foundation for further analysis and interpretation within the ISM framework.

3.2.3. Formation of the initial reachability matrix

The initial reachability matrix is obtained by transforming the self-interaction structural matrix into a binary matrix consisting of zeros and ones [48,49]. In the initial reachability matrix, the main diagonal elements are set to one, representing the direct relationship of each variable with itself. Additionally, the reliability of secondary relationships is carefully examined. This approach ensures that if variable *A* leads to variable *B* and if variable *B* leads to variable *C*, then variable *A* must also have a direct relationship with variable *C*. If there are instances where direct effects based on secondary relationships have been considered but have not actually occurred, the table should be revised accordingly to reflect these relationships accurately. The revised table should include the secondary relationship as well. The initial accessibility matrix is subsequently adjusted to achieve compatibility. This involves incorporating secondary relationships that may not initially exist in the accessibility matrix. The cells marked with 1* in the table indicate the additional relationships included in the adjusted accessibility matrix.

Table 2
STBB benefits and traditional system disadvantages.

Disadvantage of traditional systems	Advantage of blockchain-based systems	Source
High time, cost, and labor to verify and coordinate information.	Blockchain saves workforce, time, and costs by using smart contracts and shared ledgers.	[2,11,23–27]
Lack of a coordinated tracking system and using various methods for tracking management, which reduces the overall efficiency of the supply chain.	STBB systems have a distributed or shared general ledger at their core, which has several advantages.	[24–26,28–32]
Fake transactions, fraud, theft, hacking, data manipulation, non-transparency, information security, and trust.	Participants share the general ledger and use smart contracts and tokens to track changes, visibility, trust, and transparency increase. More information visibility, verification, and reduction of inappropriate transactions are possible. Information and records are immutable and can increase information security, information quality, and trust.	[2,4,11,24–26,29,31,33–43]
Environmental and social hazards, cultural barriers and linguistic differences, international regulations, and legal restrictions.	Promote sustainable products in the market and help to create an environmentally and socially sustainable supply chain.	[27,31,38,44–47]

3.2.4. Determination of relationships and leveling of dimensions and indicators

To ascertain the relationships and levels of the criteria, the accessibility matrix is used to extract the sets of outputs and inputs for each criterion. For a given variable Ci, the accessibility set represents the variables that can be reached through Ci (row elements or outputs), whereas the prerequisite set represents the variables that can access Ci (column elements or inputs).

Once the accessibility and prerequisite sets are determined, their intersection is calculated. The first variable whose intersection with the accessibility set is equal to the accessibility set (inputs) is at the first level. These first-level elements have the greatest influence within the model. After the level is determined, the criterion with the determined level is removed from all the sets. The input and output sets are then reformed, and the level of the next variable is obtained.

Following the leveling process, four distinct levels were identified. The charts pertaining to this section can be found in the Appendix, providing visual representations of the identified levels.

3.2.5. Drawing the interpretive structural model

In this step, the ISM interaction network is constructed on the basis of the levels derived from the criteria. Directed arrows are used to indicate the relationships between two variables, with the final diagram reflecting the levels obtained from the final accessibility matrix. The initial interpretive structural model is drawn, considering transferability, where higher-level criteria have less influence and are derived primarily from lower-level criteria. The greater the number of criteria at lower levels, the greater their impact on all system elements.

3.2.6. The validation process of the ISM

To enhance the validation process of our ISM model, we meticulously selected a diverse panel of experts, combining both scholarly and practical insights into the application of blockchain technology in supply chains. Our selection criteria targeted individuals with significant contributions to blockchain research, as identified through the systematic literature review of 90 articles, alongside CEOs and senior executives of leading goods tracking companies known for their pioneering work in blockchain implementation. Additionally, we sought experts with a deep understanding of blockchain technology outside the immediate scope of supply chain applications to ensure a well-rounded analysis. This included professionals and academics from various geographical regions and industries to capture a broad spectrum of experiences and perspectives on blockchain technology. The chosen experts were invited to participate in a detailed questionnaire focusing on the components and relationships within our ISM model, aimed at validating its accuracy. The feedback received was instrumental in refining our model, ensuring that it reflected not only the academic discourse but also the practical realities and challenges faced by industries in integrating blockchain for enhanced traceability.

4. Discussion

Regarding RQ1, the literature discusses the applications of STBB from two primary perspectives: field and industry applications, as well as managerial applications. While most researchers concentrate on the practical applications of STBB in specific fields and industries, some studies explore its managerial implications and applications.

For RQ2, we identified four main categories to classify the benefits and advantages of STBB. These categories include (1) workforce, time, and cost-saving benefits; (2) benefits and advantages related to general ledger management; (3) benefits associated with increased visibility, trust, and transparency; and (4) sustainability benefits. By organizing the findings into these categories, we provide a comprehensive understanding of the numerous benefits and advantages that STBB offers.

When examining RQ3, we identified 11 distinct categories to address the challenges and limitations of STBB. These categories are as follows:

(1) immature technology; (2) transaction volume; (3) technology acceptance and interoperability; (4) acceptance of operating costs, immature infrastructure, high initial investment needs, and infrastructure costs; (5) complexity in use, lack of knowledge and staff training costs, and improvement of other business processes for knowledge sharing; (6) conflict of interest in supply chain stakeholders and governance challenges; (7) data privacy issues, supply chain security, and trust; (8) immutability; (9) delay in adding data to the blockchain; (10) scalability; and (11) other limitations and challenges. By categorizing these challenges, we provide a comprehensive overview of the obstacles faced in implementing and utilizing STBB.

For RQ4, we identified two main categories that explore the future development of STBB. The first category focuses on innovation through the integration of traditional technologies available in STBB, whereas the second category examines the research on the application of emerging technologies and Industry 4.0 in the context of STBB.

RQ5 pertains to a proposed model on the basis of the literature. In this section, the position of STBB is defined as a supersystem, a subsystem, or a part of a larger system. This conceptualization helps provide a comprehensive understanding of the role and function of STBB within the broader context of SCM.

By addressing these research questions, our review contributes to the advancement of knowledge in the field of STBB and offers insights into its applications, benefits, limitations, future directions, and conceptual positioning.

4.1. STBB applications

The academic literature on blockchain-based supply chain tracking can be categorized into two main sections: 1) industries and fields of application and 2) managerial applications.

4.1.1. Industries and fields of application

Blockchain technology has been applied in various industries and fields within the supply chain. The initial use of blockchain was observed in the diamond trade, where the need for enhanced transparency and trust was prominent [4,23]. Similarly, the luxury goods sector, known for its susceptibility to fraudulent activities, also adopted blockchain technology early [8,50]. In the food industry, blockchain has been leveraged to address concerns related to origin tracking and food safety, with notable examples being the implementation of blockchain-based systems by Walmart and IBM [33]. E-commerce giants such as Alibaba and JD.com have also ventured into blockchain-based applications for managing food and pharmaceuticals [4].

The concept of "from farm to fork" has emerged as a critical trend in agriculture and food traceability, necessitating the linkage of all supply chain stakeholders to the blockchain and the sharing of relevant data to ensure traceability throughout the entire chain [7,51,52]. In the pharmaceutical industry, blockchain has been employed in various critical applications, including supply chain monitoring for manufacturers, drug authentication, serialization, distribution, clinical trials, and temperature management [5,18,53].

Furthermore, the scope of blockchain-based supply chain tracking extends beyond food and pharmaceuticals to encompass diverse sectors and industries. This includes areas such as sustainability and the environment, where blockchain has been utilized to address sustainability challenges and enhance environmental accountability [1,4,11,54]. The healthcare and automobile industries have also explored the potential of blockchain technology in improving processes and ensuring data integrity [55]. Additionally, blockchain has been applied in domains such as insurance, safety, logistics, mineral tracking, optimal resource utilization, investment, lending, financing, and the oil industry [34,53,54,56–60].

4.1.2. Managerial applications

The academic literature on blockchain-based supply chain tracking encompasses diverse areas, including efficiency enhancement, cost reduction, product lifetime estimation, activity coordination, process control, and distribution tracking [4,23,35,53]. Hald et al. [36] emphasized the potential of organizational theory in examining the intricate relationship between blockchain and SCM.

From a marketing standpoint, stakeholders can leverage tracking capabilities to differentiate their offerings, ensure quality assurance, and effectively communicate their brand values to consumers. In turn, consumers exhibit a willingness to pay for tracking services, particularly in terms of guaranteeing food safety and quality [33,61]. Notably, blockchain's integration of all network participants into a secure framework enhances overall service delivery, benefiting both buyers and sellers [6]. By embracing blockchain, retailers can capture comprehensive sales information, enabling manufacturers to obtain accurate demand data for pricing decisions [37]. Furthermore, the adoption of blockchain technology streamlines supply chains by reducing intermediation, leading to lower transaction costs, time savings, and diminished waste generation [2].

In a financial context, blockchain-based supply chain tracking offers valuable support by facilitating revenue generation through data exchange, mitigating operational inefficiencies through collaborative cost-sharing partnerships, optimizing procurement processes, and empowering data-driven decision-making [62].

Operationally, the collection of capability information in supply chains can be accomplished through various advanced technologies, including barcodes, smart tags, RFID tags, QR codes, data matrix codes, GNSSs, and sensors [3,23,33,62]. The segregation of blockchain into public and private variants enables customization on the basis of specific audience needs and preferences. Public blockchains can facilitate token transactions, whereas private blockchains serve as robust platforms for traceability endeavors [28]. Ivanov et al. [19] conducted an evaluation of tracking systems in combination with RFID and mobile devices, highlighting the pivotal role played by the IoT, cloud technology, robots, and sensors in enabling the technical implementation of these technologies. Notably, blockchain integration in these systems enhances supplier risk identification and management.

4.2. STBB's benefits and advantages

The scholarly discourse often highlights the inherent limitations of prevailing or orthodox supply chain tracking systems as a prelude to presenting alternative remedies through STBB. These drawbacks encompass issues of information manipulation, fraudulent activities, theft, corruption, insufficient trustworthiness, and transparency concerns[24,29,33,38]. Furthermore, challenges such as labor force inefficiencies, coordination deficiencies, time-related delays, inflexibility, incompatibility, and reliability issues prevail [2,25,30]. Ineffectual processes, exorbitant costs, transactional waste, resource-intensive operations, and the proliferation of intermediaries leading to diminished producer income are also widely acknowledged [2,11,17,63].

Additional challenges include cultural and linguistic barriers, international regulations, legal restrictions [2,37,38], adoption costs, and vulnerability to data breaches and manipulation [3].

Conventional tracking management within companies and organizations has historically relied upon an assortment of methods, ranging from telephone communications and email correspondences to advanced web-based systems such as electronic data interchange (EDI), value-added networks (VANs), and enterprise resource planning (ERP). However, the absence of a harmonized and synchronized system invariably undermines the overall efficiency of the supply chain. In recent years, substantial attention has been given to the integration of blockchain technology, smart contracts, and complementary tools such as the IoT and RFID to address these challenges [25]. STBB systems, distinguished by their unique real-time capabilities and automated data updates, empower efficient and effective decision-making processes. By fostering a standardized framework, participants share a common ledger and leverage smart contracts to monitor alterations, thereby eliminating the need for time-consuming data synchronization [2].

Table 2 aptly illustrates the salient drawbacks associated with prevailing supply chain tracking systems, juxtaposed against the manifold benefits afforded by STBB systems, as gleaned from scholarly research.

STBB offers a multitude of significant benefits and advantages, prominently including the amplification of trust, transparency, and security within supply chains. It plays a pivotal role in maintaining stability while concurrently diminishing waste and rework, consequently enhancing overall operational efficiency. The preservation of data integrity, coupled with legal compliance, constitutes another noteworthy advantage, along with improved data quality and real-time tracking and detection capabilities. STBB also contributes to efficient inventory management and real-time monitoring of material flow, ultimately bolstering product branding and enabling effective marketing and pricing activities [46,64–66].

In contrast to traditional methods, blockchain technology not only ensures transparency but also safeguards the privacy of individuals and companies by leveraging public and private key encryption techniques to control sensitive information [43]. Transparent product tracking holds immense significance for suppliers, and the adoption of private blockchain solutions mitigates concerns related to authentication. Leveraging blockchain for knowledge sharing in SCM yields improvements in speed, reliability, flexibility, quality, and cost [67]. Given the vast volume of daily data, blockchain serves as an effective means of managing digitized records [62]. Compared with unlicensed blockchains, authorized blockchains are widely recognized for their proven track record and adherence to well-defined protocols, providing a high level of certainty [2].

4.3. STBB's limitations and challenges

Immature technology: The immaturity of blockchain technology represents a prominent challenge, as its adoption and implementation are still in the nascent stages. Considerable efforts are required to advance the maturity of this technology, as highlighted in various studies [3,43,68]. Many companies are currently in the testing phase or adopting a cautious "wait and see" approach before fully operationalizing STBB systems. It is worth noting that blockchain technology has emerged after other transformative technologies, such as the IoT, automated tools, and Industry 4.0, which presents its own set of challenges [42]. The full potential of blockchain can be realized only when it is integrated with complementary technologies such as the IoT, enabling the provision of traceable and reliable services [28,66,69]. The integration of these technologies is crucial, as blockchain alone would be akin to an empty ledger without the support of other innovative tools and systems.

Transaction volume: Transaction volume poses a significant challenge for blockchain technology, particularly in the context of supply chain transactions characterized by a high volume of transactions. Existing blockchains have primarily been designed and optimized for value transactions, making them ill-suited for handling the large number of transactions involved in supply chain processes [11,41,69].

Technology acceptance and interoperability: The acceptance and interoperability of blockchain-based supply chain tracking systems present formidable obstacles, stemming from factors such as system architecture, the absence of a well-defined framework, and complexities in integrating with existing infrastructures [33,65,70]. Achieving comprehensive traceability necessitates active engagement and consensus among all supply chain stakeholders regarding data sharing protocols. Ensuring motivation alignment becomes paramount in fostering acceptance, as concerns over privacy and limited broadband accessibility in rural areas can impede widespread adoption [2,33,37]. Overcoming these challenges entails addressing privacy apprehensions, aligning incentives, and enhancing the connectivity infrastructure.

Immature infrastructure and high initial investment needs: The immaturity of infrastructure and the substantial initial investment required pose significant challenges in adopting blockchain-based supply chain tracking. These challenges encompass the readiness of blockchain infrastructure, the need for process modifications, hardware components, and the high fees associated with block transactions [33,66,71]. The incorporation of emerging technologies such as the IoT and AI can further complicate the implementation process for business participants [23]. Companies must carefully evaluate the potential benefits and cost implications before committing to such investments [33]. Moreover, ongoing technology maintenance costs and the need to integrate blockchain with existing systems, such as ERP or customer relationship management (CRM) systems, present additional challenges [69,72,73]. Data quality is also a crucial consideration, as ensuring accurate and reliable data entry by network participants may require training, technical support, and continuous education [41,74].

The complexity of use: The intricate nature of implementing blockchain in supply chain tracking poses a formidable challenge, given the complex mathematical and computational requirements involved [41,42,75]. The adoption of this technology necessitates a profound understanding and expertise in the field [41,42,75]. Moreover, resistance to embracing blockchain due to traditional attitudes can be effectively addressed through the provision of tailored training courses and educational programs [43,72,75].

Conflict of interest among supply chain stakeholders: The presence of conflicting interests among supply chain stakeholders poses a significant obstacle to information sharing, particularly when sensitive data related to sustainability parameters are involved. The advent of digital technologies has the potential to exacerbate social, political, and territorial control, leading to issues of deprivation or expropriation [46,58,74,75]. In the supply chain context, each stakeholder adheres to different governance policies, making it challenging to streamline processes across organizations. The governance challenge lies in establishing a consensus on specific transactions, requiring supply chain actors to navigate government policies and meet the demands of sustainable market competitiveness before implementing any changes [11,62,74].

Data privacy issues, supply chain security, and trust: Preserving data privacy, ensuring supply chain security, and establishing trust are crucial and complex challenges in the realm of traceability. It is imperative to enforce access control based on confidentiality requirements defined by the information owner, limiting the visibility of sensitive information to relevant stakeholders [65,71]. The reliability of traceability information is a persistent concern, as certain key actors still rely on non-automated methods of information management, which can lead to inconsistencies and inaccuracies [69,70].

Cybersecurity has emerged as a significant issue within the IoT domain, as data breaches in vast databases can have detrimental consequences for businesses, underscoring the necessity for robust privacy measures [62]. Establishing trust in the technology itself poses another formidable challenge, as the loss or damage of a node's private key in a blockchain system can render the entire infrastructure unusable, thereby raising concerns about its reliability [6]. Moreover, the susceptibility of RFID tags, which are commonly employed for data tracking purposes, damage, and inefficiency further compound the trustworthiness and effectiveness of traceability systems [76].

In the case of private blockchains, the level of transparency afforded to participating entities can vary, influencing trust levels and their willingness to share crucial data, thus requiring careful consideration and management [33].

Immutability: Blockchains face the limitation of immutability, meaning that once data are entered into the blockchain, they cannot be deleted or altered, making them irreversible [74,77].

Time latency: Time latency is a notable challenge in blockchain implementation, as it often takes a considerable amount of time to add data to a blockchain, resulting in delays in commercial deployment [33,69,70].

Scalability: Scalability is a significant challenge in blockchain technology, particularly in multi-layered supply chains where numerous transactions must be processed quickly. STBB systems may face scalability issues because of the time required for transaction confirmation [37,56,70].

Other challenges: In addition to the previously mentioned challenges, several other limitations and obstacles are associated with STBB systems. Legal issues and the absence of established standards and protocols pose challenges to their implementation [25,33,71]. The access to information in diverse social cultures and the unpredictable behavior of individuals in a network further complicate the adoption of STBB [65]. There is also concern of illegal activities by those who attempt to evade registration and monitoring within the blockchain system.

Furthermore, in less developed countries, the traditional paper-based approach to supply chains remains prevalent, and companies often prefer to utilize existing integrated enterprise information systems such as ERP to avoid high costs [8]. Some scholars have noted a potential decline in job opportunities due to the advancement of blockchain systems.

4.4. STBB's future development

The implementation of previous technologies such as EDI facilitated the transition from paper-based transactions to digital transactions, leading to diverse benefits such as cost reduction, improved processing speed, decreased errors, and enhanced partner traceability. Blockchain technology has the potential to revolutionize supply chain systems. However, rather than being seen as alternative technologies, EDI and blockchain can complement each other. EDI serves as a mechanism for information sharing, which can be stored and processed by blockchain technology [2].

The recognition of the need for additional technologies to address limitations in STBB has opened opportunities for leveraging various technologies alongside blockchain. Researchers have explored the integration of blockchain with assistive technologies such as the IoT and RFID to overcome challenges [19,62,68,70]. By identifying and understanding the interrelationships among these challenges, barriers to the development and implementation of blockchain in the supply chain can be addressed [8,28,65,74]. The evolution towards physical-cyber supply chains is anticipated as a future development [19]. The emergence of Industry 4.0 has created opportunities to enhance operations by integrating technologies such as the IoT, blockchain, AI, 3D printing (3DP), and big data analytics (BDA) in hybrid supply chains [19,25,28,78]. The IoT enables the combination of software, sensors, data networks, and blockchain mechanisms, while smart contracts enable remote system management, increased efficiency, and improved cost monitoring. The integration of AI, blockchain, and IoT addresses scalability, time latency, digital trust, security, and source assurance challenges [62]. Hybrid blockchains, characterized by modularity, robustness, and cost savings, can offer traceability without requiring the complete replacement or reconstruction of the supply chain, leveraging existing technologies such as QR codes [3].

Blockchain systems offer innovative features that help overcome obstacles and limitations in supply chains. These features include physical transaction approval, privacy and licensing mechanisms, scalability, reduced hardware requirements, and lower operating costs [65]. The utilization of RFID tags and online verification codes in supply chains enhances transparency and stability, while blockchain encryption capabilities ensure the validity and security of the data [11]. To address security issues in blockchain-based open-access systems, Liu and Li [23] proposed a hierarchical definitive wallet technique. Additionally, QR codes are considered an advancement over linear barcodes because of their higher data storage and encryption capabilities, as well as their environmental friendliness [8].

In the future, blockchain technology is expected to bring significant value to supply chains, particularly in terms of broad vision and product traceability [16]. Product traceability is likely to be the area where blockchain will be widely deployed. There will also be a growing focus on using environmentally friendly materials and promoting social sustainability in the production phase [4,45].

Currently, automated identification technologies such as barcodes and RFID are widely used for tracking supply chains through ICT applications. RFID-based tracking systems have gained prominence in recent years and have been the subject of numerous academic studies [8,25]. Future research should explore the interoperability between blockchain and IoT devices, such as RFID, to enhance our digital lifestyle with greater automation and intelligence [25,70].

Decentralized finance (DeFi) presents exciting opportunities and the potential to create an open, transparent, and immutable financial infrastructure [30]. Collaborative partnerships among businesses throughout the supply chain have a positive effect on performance, profits, and customer satisfaction. Implementing such partnerships requires advanced solutions to mitigate potential adverse effects, especially considering emerging trends such as the IoT, which can lead to short-term business relationships without prior trust [53].

The traditional invoicing process is likely to become obsolete in the future, as purchase orders recorded on the blockchain become immutable digital entities [26]. Smart contracts based on blockchain technology are also a noteworthy development [33]. Future work should address technical issues related to scalability, security, and decentralization in blockchain systems [65].

Further research endeavors should prioritize the exploration of blockchain publication practices, the adoption of blockchain technology, its social impacts, and its implications for management. Given that blockchain technology is still in its nascent stages, researchers should conceptualize future investigations on the basis of current issues and challenges [67].

4.5. STBB's modeling classification

The inclusion of a separate section on modeling is deemed necessary to provide a systematic analysis of the reviewed articles that specifically address modeling. This section serves the purpose of classifying the models based on several key components, including the model title, the role of tracing within the system (whether as a system, subsystem, or component), the positioning of tracing within the model, the placement of blockchain within the model, and the positioning of the supply chain within the model.

This delineation categorizes traceability functions as either a comprehensive system overseeing transparency across the entire supply chain, a focused subsystem within specific segments, or a supportive component to broader systems. This approach highlights the multifaceted impact of blockchain technology in facilitating traceability, from foundational enhancements to targeted improvements within SCM.

The classification process considers the hierarchical structure of the concepts examined within each model. Three primary concepts are explored in the models, namely, tracing, blockchain, and supply chains. If a concept does not possess a lower level than itself in the model, it is regarded as a component of the system. Conversely, if a concept lacks a higher level, it is categorized as a supersystem. In cases where a concept is associated with a higher-level concept, it is identified as a subsystem. A comprehensive overview of the classification of the reviewed article models can be found in Table 9 in the Appendix, which provides valuable insights into the categorization process.

By adopting this structured approach for analysis, the relationships and positioning of tracing, blockchain, and supply chains within the reviewed models are elucidated, facilitating a deeper comprehension of their respective roles and interactions within the broader system context, as elucidated in the articles under examination.

The analysis of the reviewed models reveals that tracking is considered a subsystem, with a focus on its primary role and output. Blockchain is commonly positioned as a subsystem, emphasizing its supportive function in enhancing tracking capabilities. The supply chain is identified as the primary application area for blockchain-based tracking. These findings contribute to understanding the role and interrelationships of tracking, blockchain, and the supply chain in modeling efforts, facilitating future research and development in this domain.

4.6. Contradictions in STBB's studies

In our analysis, we uncovered a series of intriguing contradictions and anomalies when comparing our conclusions with the existing body of literature. These discrepancies are related primarily to the perceived benefits and challenges of implementing blockchain technology within supply chains.

First, our study highlighted substantial optimism regarding blockchain's capacity to enhance transparency, efficiency, and security in SCM. This perspective aligns with the positive outlook shared by Pournader et al. [11] and Wang et al. [16], who underscored blockchain's transformative potential in ensuring traceability and reducing counterfeit products. However, this view contrasts with the concerns raised by Amentae et al. [17] and Mahyuni et al. [18] regarding blockchain scalability and the significant initial investment required for its adoption. These concerns point to an underlying tension between the theoretical benefits of blockchain and the practical challenges faced by companies during implementation. The contradiction may stem from the evolving nature of blockchain technology and its application across different industries, suggesting that while the technology holds promise, its full integration into supply chains is still a work in progress.

Second, our findings on the integration of blockchain with other technologies, such as the IoT and RFID, to improve supply chain traceability presented another area of discrepancy. While we, along with Ivanov et al. [19], advocate for the synergy between blockchain and these technologies as a future trend, the existing literature, such as the work by Saberi et al. [10], reveals a gap in the practical application of these integrations. The literature suggests that while the conceptual framework for integrating blockchain with IoT and RFID is well established, real-world applications are still limited, indicating a lag in the operationalization of these integrated technologies. This discrepancy might be attributed to technical complexities, interoperability issues, and the need for standardized protocols to facilitate seamless integration between blockchain and other technological systems.

These contradictions and anomalies underscore the need for ongoing research and development to address the gaps between the theoretical benefits and practical implementation challenges of blockchain in supply chains. Moreover, they highlight the importance of industry-specific studies to understand the contextual factors influencing the adoption and integration of blockchain and other technologies within diverse supply chain settings.

5. ISM model and proposed research framework

This study employed expert opinions and ISM to identify the level of influence among different components. The resulting model consists of four levels, with indicators at lower levels exerting less influence. The higher-level components have the most influence, whereas the lower-level components are the most affected within the model. Intermediate levels (second and third levels) consist of components that possess a certain degree of influence and effectiveness on other system components. The main components among the supply chain components in the context of blockchain and the answers to RQ6 are shown in Fig. 4.

The findings highlight that the components at the fourth level, or the final level, exhibit the strongest connections and impact on other dimensions. Notably, mature technology, mature infrastructure, and high initial investment indicators are positioned at the lowest level of the ISM

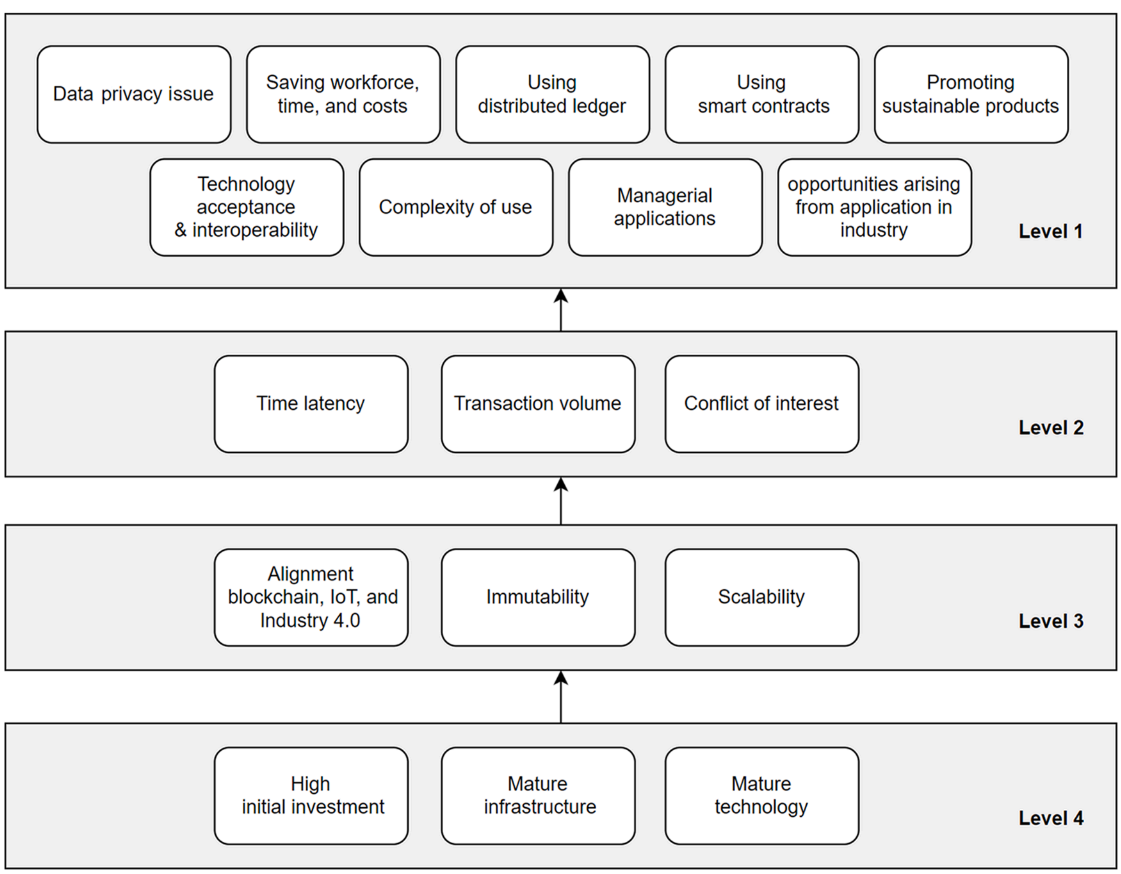

Fig. 4. The basic model developed via the ISM method.

model, underscoring their considerable influence on other indicators. These components serve as the foundation and prerequisites for the development of the supply chain on the basis of blockchain technology. Therefore, policymakers should prioritize initiatives that facilitate the deployment and advancement of these components. Focusing on these foundational components is crucial for the development of the blockchain-based supply chain industry.

The alignment of blockchain, the IoT, and Industry 4.0, immutability, and scalability components is positioned at the subsequent level. The remaining components at two levels are influenced by their respective lower-level components. At the first level, the dependent elements of the blockchain industry hold paramount importance and have dependencies on other elements that enable the tracking of the supply chain through blockchain. These components are considered the most affected components, exhibiting mutual relationships with one another. Notably, technology acceptance and interoperability are among the indicators within this level.

The critical issues in STBB research can be summarized through the research questions, which provide a coherent framework. RQ1 focuses on STBB applications, considering specific industries and managerial perspectives. RQ2 explores the benefits of STBB over traditional methods, highlighting workforce, time, and cost savings; the benefits from distributed ledgers, smart contract usage, and the promotion of sustainable products. RQ3 addresses the limitations and challenges of STBB, including immature technology, transaction volume, acceptance and interoperability, infrastructure and investment requirements, complexity of use, stakeholder conflicts, data privacy, supply chain security and trust, immutability, time latency, and scalability. RQ4 examines the integration of blockchain with other technologies, such as the IoT, RFID, and Industry 4.0, as an upcoming trend. Finally, RQ5 analyzes STBB as a subsystem, supersystem, or component within the overall system. This review provides a comprehensive classification and summary of the STBB research framework, as presented in Table 3.

6. Conclusions

This systematic literature review provides valuable insights into the role of blockchain in supply chain traceability. The study addressed key research questions and explored various aspects related to the applications, benefits, limitations, future technologies, and modeling methods of STBB.

This review highlights the diverse applications of STBB in specific industries and managerial contexts, highlighting its potential to revolutionize supply chain operations. The benefits of STBB were discussed, emphasizing advantages such as workforce, time, and cost savings; the utilization of distributed ledgers; the implementation of smart contracts; and the promotion of sustainable products. On the other hand, the challenges facing STBB were identified, including issues related to technology maturity, transaction volume, technology acceptance, interoperability, infrastructure readiness, complexity, conflicting interests among stakeholders, data privacy, security, trust, immutability, time latency, and scalability.

Table 3
STBB categories of topics.

STBB field of research	Category of topics
Applications	- Application in a specific field or industry - Managerial applications
Benefits and advantages	- Saving workforce, time, and costs - Benefits arising from distributed or shared general ledger - Benefits arising from using smart contracts - Promoting sustainable products
Limitations and challenges	- Immature technology - Transaction volume - Technology acceptance and interoperability - Immature infrastructure and high initial investment needs - Complexity of use - Conflict of interest in supply chain stakeholders - Data privacy issues, supply chain security, and trust - Immutability - Time latency - Scalability
Future developments	Combination of blockchain with other technologies such as the IoT, RFID, and Industry 4.0
Modeling	STBB as a subsystem, supersystem, or component in the overall system

The model proposed in this study facilitates the systematic determination of causal relationships among components within the context of supply chain traceability via blockchain. It serves as a valuable instrument for identifying, categorizing, and synthesizing these relationships, thereby empowering policymakers and industry stakeholders to devise more effective strategies and optimize resource allocation. By comprehending these intricate relationships, supply chain efficiency and effectiveness can be enhanced through informed decision-making and initiative-taking improvements, thus yielding tangible benefits in terms of operational performance and outcomes.

Future research directions were also identified, focusing on the integration of blockchain with emerging technologies such as the IoT, RFID, and Industry 4.0. Additionally, the review emphasized the importance of considering STBB as a subsystem, supersystem, or component within the overall supply chain system. Based on the identified categories and findings, a comprehensive framework for understanding and analyzing STBB in the supply chain context was proposed.

This study contributes to the existing body of knowledge by synthesizing and analyzing the literature on the role of STBB in supply chain traceability. It is hoped that this review will inspire further research and development efforts in this area, enabling the realization of enhanced transparency, efficiency, and sustainability in global supply networks through the adoption of blockchain-based traceability solutions.

Data availability statement

This study is predicated on a systematic literature review. Consequently, it does not necessitate primary data collection or experimental undertakings but relies on data extracted from a recognized academic database.

- **Data source:** The foundation of this article's findings is data retrieved solely from the Scopus academic database. These data encompass peer-reviewed scientific journals, conference proceedings, and other authoritative publications pertinent to the domain of this study.
- **Review methodology:** Adherence to the PRISMA methodology was maintained to ensure a transparent, consistent, and reproducible review process. The methodology section of this article provides a detailed account of the search strategy, as well as the inclusion and exclusion criteria applied.
- **Access to data:** All sources consulted and referenced in this study are systematically enumerated in the reference list. While open-access articles can be directly procured online, certain articles might necessitate appropriate subscriptions or permissions due to paywalls. For added transparency, the datasets synthesized and examined for this study are available from the corresponding author upon reasonable request.
- **Inquiries:** Readers with additional queries or those requiring access to the study's data are invited to contact the corresponding author. The pertinent contact details are provided in the author information section of this article.

CRediT authorship contribution statement

Reza Payandeh: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources,

Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. **Ahmad Delbari:** Investigation, Writing – original draft. **Fatemeh Fardad:** Data curation, Investigation, Resources. **Javad Helmzadeh:** Data curation, Investigation, Resources. **Sanaz Shafiee:** Formal analysis, Methodology, Writing – original draft, Writing – review & editing. **Ali Rajabzadeh Ghatari:** Formal analysis, Investigation, Methodology, Supervision, Validation, Writing – original draft, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Supplementary materials

Supplementary material associated with this article can be found in the online version at doi:10.1016/j.bcra.2024.100240.

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