MSc Program
Engineering Management

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Leveraging Blockchain Technology for Sustainable, Transparent and Efficient Supply Chain Management: An Integrative Exploration from an Engineering Management Perspective

A Master's Thesis submitted for the degree of
“Master of Science”

supervised by
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Vienna, 20.04.2024

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Affidavit

I, **HESAM ALDIN FATTAHI BAFGHI, BSC**, hereby declare

1. that I am the sole author of the present Master's Thesis, "LEVERAGING BLOCKCHAIN TECHNOLOGY FOR SUSTAINABLE, TRANSPARENT AND EFFICIENT SUPPLY CHAIN MANAGEMENT: AN INTEGRATIVE EXPLORATION FROM AN ENGINEERING MANAGEMENT PERSPECTIVE", 201 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
2. that I have not prior to this date submitted the topic of this Master's Thesis or parts of it in any form for assessment as an examination paper, either in Austria or abroad.

Vienna, 20.04.2024

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Signature

Abstract

This master's thesis aims to explore the potential of blockchain technology in improving supply chain management by leveraging engineering management principles and emerging technologies, specifically blockchain. This research will seek to enhance sustainability, transparency, efficiency within supply chains through a comprehensive literature review, it will identify challenges in supply chain management and examine how blockchain can address them. To achieve that, we need to address the definitions of sustainability, transparency, and efficiency in supply chains.

A sustainable supply chain focuses on integrating environmental, social, and economic considerations (Luther, 2020) into its operations to minimize negative impacts and promote long-term sustainability. While specific specifications may vary depending on the industry and company, there are some key elements commonly associated with a sustainable supply chain (Bateman et al., 2019) that are worth considering, as follows:

Environmental Stewardship (Reyes-Soriano et al., 2022), Ethical and Responsible Sourcing (Gimenez et al., 2012), Supply Chain Transparency (Kazancoglu et al., 2008), Collaboration and Partnerships (Seuring and Müller 2008), Risk Assessment and Management (Detwal et al., 2023), Life Cycle Assessment

(Gao et al., 2017), Circular Economy Practices (Brandenburg et al., 2018), Stakeholder Engagement and Communication (Ahi et al., 2011), Compliance and Certifications (Govindan et al., 2016), and Continuous Improvement (Detwal et al., 2023).

By incorporating these specifications, a sustainable supply chain strives to create positive environmental and social impacts while maintaining economic viability. It promotes responsible sourcing, reduces waste and emissions, fosters stakeholder collaboration, and contributes to a more sustainable future. (Montecchi et al., 2021)

A transparent supply chain refers to a system where the flow of information, data, and processes within the supply chain is open, visible, and accessible to relevant stakeholders. It aims to provide real-time visibility into various aspects of the supply chain, including the movement of goods, inventory levels, production processes, and transactions. While the specific specifications may vary depending on the industry and company (Qimaone, 2023)., here are some key elements commonly associated with a transparent supply chain:

Data Visibility (Detwal et al., 2023), Technology Infrastructure (Gao et al., 2017), Traceability (Brandenburg et al., 2018), Collaboration and Communication (Kazancoglu et al., 2008), Compliance and Standards (Gimenez et al., 2012), Risk Management (Seuring et al., 2008), and Performance Measurement (Ahi t al., 2011).

Overall, a transparent supply chain aims to foster trust, accountability, and efficiency by providing stakeholders with visibility and access to relevant information. It enables proactive decision-making, reduces uncertainties, and facilitates collaboration among supply chain partners. (Detwal et al., 2023), (Schäfer, 2023), (Qimaone, 2023).

An efficient supply chain is designed to minimize costs, reduce waste, and optimize the flow of goods and information from suppliers to customers (Jenkins, 2022) While specific specifications

may vary depending on the industry and company, here are some key elements commonly associated with an efficient supply chain:

Demand Planning and Forecasting (Negi et al., 2021), Lean Inventory Management (Gunasekaran et al., 2004), Supplier Relationship Management (Mulakawa., 2023), Streamlined Processes, Transportation and Logistics Optimization, Data Analytics and Technology Integration (Matopoulos et al., 2015), Continuous Improvement (Negi et al., 2021), Customer Focus, Sustainability and Environmental Considerations (Matopoulos et al., 2015), Performance Measurement (Gunasekaran et al., 2004).

By incorporating these specifications, an efficient supply chain aims to achieve cost-effectiveness, responsiveness, and customer satisfaction while optimizing the use of resources and minimizing waste (Negi et al., 2021).

Considering all the above definitions, the research will investigate the main principles of engineering management, such as technical understanding, systems thinking, process optimization, innovation and technology adoption, data analysis, decision-making, and continuous improvement, and how the research subject would meet those principles. (Study Smarter, 2023)

The proposed methodology will involve a qualitative method approach and may have an integrative exploration approach that involves integrating multiple perspectives (West, 2013), such as engineering management and blockchain technology, to gain a holistic understanding of the subject matter (Seuring et al., 2022). To address the research questions, data collection method is to consider using a combination of primary and secondary data sources (Golicic et al., 2012).

Data will be collected from academic sources and relevant databases and analyzed to develop a conceptual framework. Primary data collection methods may include interviews, surveys, or focus groups (Montecchi et al., 2021) with supply chain professionals, blockchain experts, and engineering management practitioners, while secondary data sources may include academic papers, industry reports, and case studies (Raghavarapu et al., 2016).

This research aims to discuss analyzing blockchain's decentralized nature (Gaur et al., 2020), cryptographic security, and immutability, and may explore integration with IoT, smart contracts, and data analytics. Case studies and simulations (Jia et al., 2023) will validate the proposed concepts. The findings will contribute to understanding the benefits, challenges, and implementation considerations of adopting blockchain in supply chain management.

The research will analyze the collected data for qualitative data, through thematic analysis to identify patterns (Montecchi et al., 2021), themes, and insights from interviews or open-ended survey responses, and the author may use statistical analysis to examine relationships and patterns between variables (Gugueoth et al., 2023), such as blockchain adoption, transparency, and supply chain efficiency.

Afterward, the research will have a deep look at case studies and empirical evidence. Several case studies and empirical research (Gaur et al., 2020) provide evidence of the benefits and limitations of leveraging blockchain for supply chain management. These studies can demonstrate successful implementations in various industries, such as food, retail, and pharmaceuticals, where blockchain improves traceability and enhances supply chain resilience (Jia et al., 2023). However, the literature also acknowledges the need for further empirical

research and scalability testing to validate blockchain's effectiveness across diverse supply chain contexts while also addressing the limitations and problems that may be caused by leveraging blockchain in the supply chain (Montecchi et al., 2021).

While blockchain technology holds great potential for supply chain management, several challenges need to be addressed (Wannenwetsch et al., 2023). Studies highlight scalability concerns, interoperability issues, technical complexity, data privacy and confidentiality, adoption and network effect, high energy consumption, and regulatory and legal implications.

These issues should be considered limitations and problems that leveraging the blockchain in the supply chain may create, and we should address them. Furthermore, the integration of blockchain requires collaboration and coordination among multiple stakeholders (Deloitte, 2023), which may pose organizational and governance challenges. It's important to note that while these limitations and problems exist, many of them can be addressed through ongoing research, technological advancements, and collaborative efforts among industry stakeholders. The literature emphasizes the need for careful planning, strategic adoption, and tailored implementation approaches (Gaur et al., 2020).

Collaboration between engineering management professionals, supply chain experts, and blockchain developers will be emphasized.

Keywords: Blockchain, Supply chain, Sustainability, Transparency, Efficiency, Automation

Table of Contents

List Of Figures

List of Tables

1 Introduction

1.1 Overview of study

2008 saw the invention of blockchain technology by an anonymous individual or individuals going by the name Satoshi Nakamoto. Bitcoin was its initial use case, and it subsequently spawned other crypto currencies. Undoubtedly, the financial industry has benefited the most from this innovation, but that doesn't mean that other applications can't be made, particularly in supply chain management.

Blockchain is a distributed database or ledger that runs concurrently on a large number of nodes" possibly millions" that can be dispersed across numerous organizations and individuals as well as geographically (Swan, 2015). Based on the framework described, the distributed ledger shares data on a peer-to-peer network. "Network members (nodes) communicate and verify data according to a predefined protocol without central authority." Block Chain Technology is extremely secure, compared to the centralized approach, which raises concerns about trust in current technologies.

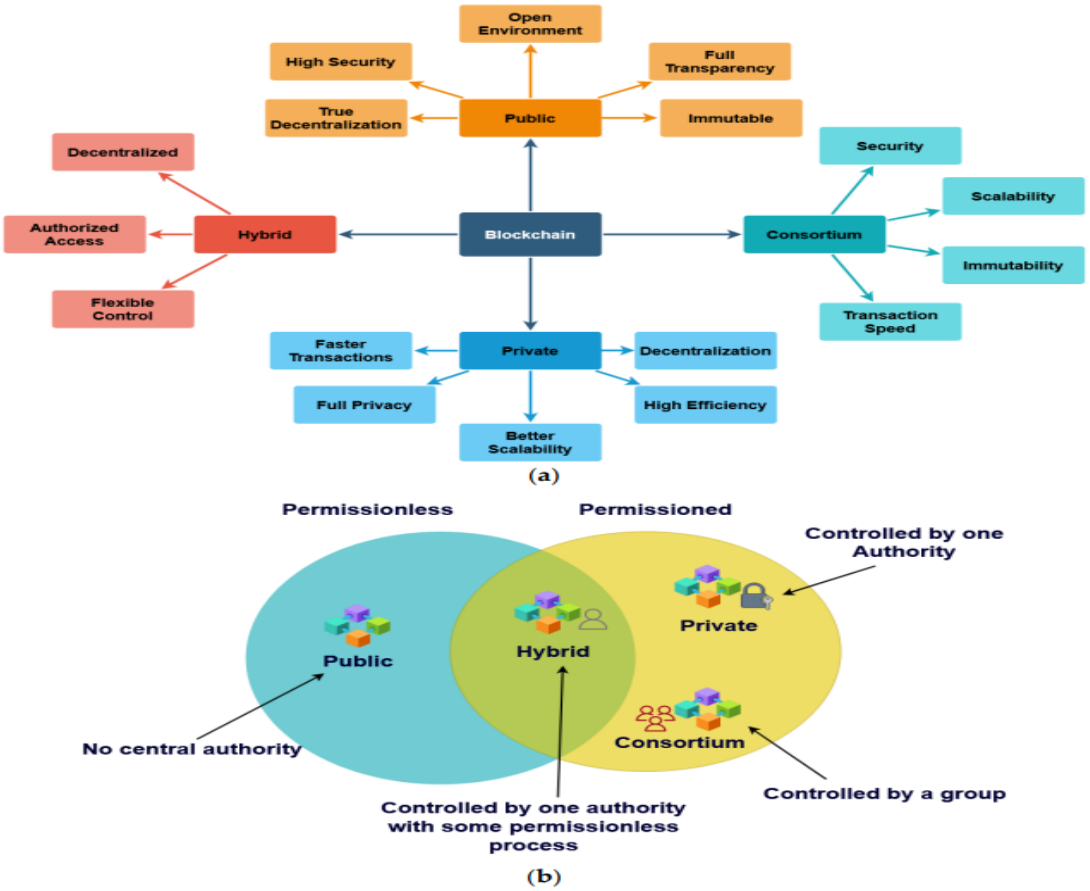

Figure 1. (a). Features of Blockchain. (b). Difference between various blockchain (Uddin et al., 2023)

TechnologiesDistributed ledgers can be centralized, granting certain users special rights, or decentralized, granting all users equal rights (Esmaeilian et al., 2020). Three subcategories of networks public, private, and federated blockchains Figure 1. can be created using these structures. In contrast to public blockchains, which allow anyone (node) to join without identification and transact without authorization, permission-based blockchains are those found in both private and amalgamated networks (Sunmola, 2021).

Nevertheless, no matter what strategy a blockchain implementation chooses, network node transparency cannot be jeopardized. BCT has more potential than just its decentralized nature because of its additional features, which include distributed ledgers, immutability, consensus, and smart contracts. With this technology, every data block can be uniquely identified using the hash value produced by the cryptographic function.

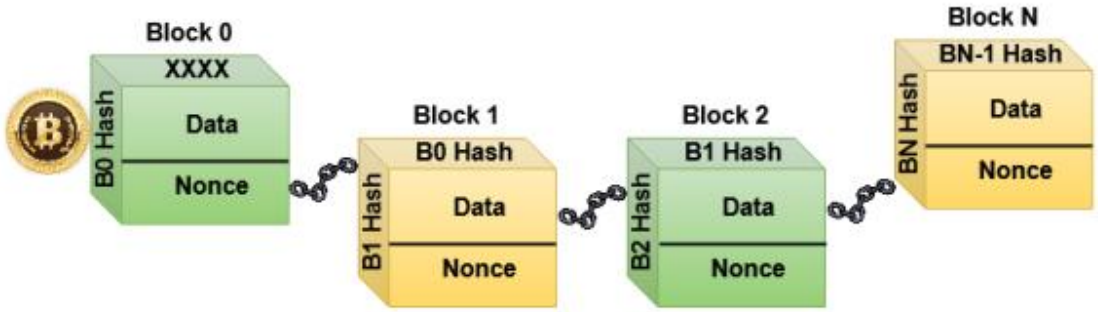

Figure 2. Structure of Blockchain. (Uddin et al., 2023)

A cryptographic hash function guarantees that a small, unexpected change in the hash code will occur from a single bit change in the block contents (Sreerakhi et al, 2022). Each new block in a chain is constructed by including both the hash code and the actual data of the previous block. Each block of data, as depicted in Figure 2., consists of the following subjects: The hash values of the previous and current blocks, transaction data, and the Nonce message. Blockchain is a helpful technology that may be utilized in different areas of a big network and is believed to be a workable solution for streamlining global supply chains.

A trade transaction is the most complicated kind of transaction. Transaction cooperation is a multi-party process that depends on paper documents, which require a lot of resources, cause delays in transactions, and impede the smooth flow of goods. When smart contracts replace traditional paper contracts and digitalization and independent reading features are introduced, the ecosystem as a whole will gain from enhanced collaboration. Because distributed ledger technology removes the possibility of illicit activity and content creation, it can be used to efficiently monitor, record, and measure environmental sustainability.

The blockchain-based operating system may make it possible to digitize manual records and establish a safe, public network for the purpose of managing blockchain data, data monitoring, and risk reduction. The internet of things (IOT) and artificial intelligence (AI) are two recent innovations that significantly improve BCT for supply chain management (Christidis et al., 2016). Research has indicated that integrating blockchain technology with IoT and smart contracts can

result in a smooth supply chain automation environment. This can result in significant cost and time savings as well as cryptographic verifiability.

Organizations nowadays are constantly looking for novel approaches to incorporate ICT into their operations in order to reap long-term benefits (Carrera & Kurnia, 2015). Information and communication technology (ICT) intervention is a promising strategy to improve the efficiency of supply chain (SC) processes, as evidenced by recent developments in the field (Queiroz & Wamba, 2019).

Additionally, prior research has shown that ICT improves SC integration (SCI) to manage a significant rise in the volume and complexity of information shared amongst different SC partners (Prajogo et al., 2012). Additionally, it is predicted that Industry 4.0 techniques enabled by ICT will improve process integration, leading to long-term organizational performance (Lu et al., 2017; Kamble et al., 2018). Blockchain is a well-known technology that has enormous potential to address the complexity of SC (Hofmann et al., 2018; Viryasitavat et al., 2020).

In order to add value to activities like product tracking, information sharing, and transparency in SC transactions, blockchain technology (BT) is an organisational capability that unifies all SC assets and resources (Aste et al., 2017; Korpela et al., 2017).

BT improves the credibility and dependability of the SC network when combined with other cutting-edge technologies like cloud computing (Liu et al., 2017), robotics systems (Mueller et al., 2017), Internet of Things (IoT) (Yang et al., 2017), big data analytics (Belhadi et al., 2019), cybersecurity (Yu et al., 2017), and simulations and prototypes (Ramadan et al. 2017).

By storing all SC transactions in a secure location that is easily accessible to all SC partners, BT raises the SCI level (Biswas et al., 2017). BT has the ability to improve the SCI, which would support sustainability and business excellence. As a result, the main goal of this research is to evaluate how employing blockchain technology can contribute to an efficient, transparent, and sustainable supply chain.

The study was carried out with the specific objective of investigating the impact of Blockchain technology on an efficient, transparent, and sustainable supply chain from the standpoint of engineering management.

Summary

This chapter applies engineering management principles to examine how blockchain technology can improve supply chain management. It delves into the benefits of blockchain, such as fostering collaboration, transparency, and sustainability within supply chains. The research aims to assess how blockchain can positively impact supply chains by addressing challenges through strategic planning and adoption. Data collection methods include interviews, surveys, and case studies to gain insights into the benefits, limitations, and implementation considerations of blockchain in supply chain management. In order to promote long-term sustainability, the study also focuses on the essential elements of a sustainable supply chain, highlighting the integration of environmental, social, and economic factors. Additionally, it examines the principles of engineering management to optimize efficiency, responsiveness, and customer satisfaction in supply chain operations.

The research aims to offer a comprehensive understanding of how blockchain technology can contribute to an effective, transparent, and sustainable supply chain ecosystem by using this methodology and integrating various points of view.

2 Scope of work

2.1 Background

In recent times, there have been significant transformations in supply chain management due to the demands for enhanced efficiency, transparency, and sustainability. Blockchain technology has surfaced as a viable approach to tackle these issues, providing a safe and unchangeable distributed ledger mechanism for documenting and monitoring supply chain dealings.

Using trustworthy citations from earlier relevant studies, this research background section will examine how blockchain technology might be used to achieve transparent, sustainable, and effective supply chain management initiatives. The use of blockchain technology in supply chain management has been the subject of many studies, which have shown how it can enhance transparency, traceability, and trust (Dutta et al., 2020; Moosavi, 2021). In the food industry, this technology can be especially beneficial as it can increase trust and visibility (Rogerson, 2020).

It has been found to lower transaction costs and increase customer benefits (Corengia, 2019). Still, there are obstacles to overcome, such as the requirement for consumer support and the possibility of fraud and human error (Rogerson, 2020). Blockchain is viewed as a sustainable innovation that can be used to accelerate industry adoption despite these obstacles (Valle, 2020).

Supply Chain Sustainability with Blockchain: Supply chains can become more sustainable by utilizing blockchain technology, which offers traceability and transparency. Blockchain technology makes it possible to track goods and materials all the way through the supply chain, which makes it possible to identify and stop unsustainable practices like the mining of conflict minerals and deforestation. Blockchain can also help create circular supply chains, which reuse and recycle materials to cut down on waste and environmental impact (Kamble et al., 2021; Govindan et al., 2020).

Blockchain Technology for Sustainable Supply Chains: By offering a shared, unchangeable record of every transaction, blockchain technology can improve supply chain transparency. Transparency can enhance the quality and safety of products while lowering fraud, corruption, and counterfeiting. By learning more about the provenance and journey of products, consumers can make more ethical purchases and encourage ethical consumption (Hofmann et al. 2019; Wang, 2020).

Efficient Supply Chains with Blockchain Technology: Supply chains can operate more efficiently thanks to blockchain technology, which simplifies procedures, lowers paperwork, and automates transactions. Automating agreements and payments is possible with smart contracts, and since blockchain technology is distributed, there is no need for middlemen, which lowers costs and delays. Additionally, blockchain can facilitate real-time data sharing and collaboration among supply chain participants, enhancing coordination and decision-making (Zheng et al., 2019; Tran et al., 2021).

Supply chain management could be completely changed by blockchain technology since it makes processes more transparent, sustainable, and efficient. This research background section examined the current state of blockchain research in supply chain management, emphasizing key benefits and applications. The following sections of the master's thesis will go into greater detail about the literature review, the challenges and effects of incorporating disruptive technologies into

supply chains, and future research directions for blockchain technology in supply chain management.

2.2 Methodology

An essential part of the research process is the methodology chapter in this master's thesis on leveraging blockchain technology for sustainable, transparent, and efficient supply chain management from an engineering management perspective.

Its primary objective is to conduct an exhaustive review of the literature, carefully analyzing and condensing prior scholarly works, corporate briefs, and case studies pertaining to supply chain management and blockchain technology. The chapter's objective is to provide a solid theoretical and practical framework for comprehending the ramifications and complexities of blockchain technology in the context of transparent, efficient, and sustainable supply chain management.

This chapter employs a literature review methodology to critically assess the body of knowledge currently known in the field, address important research questions, and spot emerging trends.

The methodology chapter is crucial in influencing the talks and findings that follow in this thesis because it establishes the framework for a detailed investigation of the possible effects of blockchain technology on efficient, transparent, and sustainable supply chains (Henry et al., 2023).
Through this literature review methodology, the chapter endeavors to address key research questions.

2.3 Research Questions

Through this literature review methodology, the chapter endeavors to address key research questions, such as:

Research Question 1

In order to promote sustainability, how can blockchain technology help integrate social, economic, and environmental factors into supply chain operations?

Research Question 2

In what ways can blockchain technology address challenges related to data visibility, traceability and risk management in supply chains to enhance transparency?

Research Question 3

How can blockchain technology contribute to achieving cost-effectiveness, responsiveness and customer satisfaction by optimizing key elements of an efficient supply chain?

Research Question 4

What is the role of engineering management principles (such as: technical understanding, system thinking and process optimization in the successful integration of blockchain technology into supply chain management?

As mentioned above this chapter will discuss on the impact of blockchain technology on supply chain transparency, sustainability, and efficiency.

In addition, the methodology chapter looks for gaps in the literature and highlights best practices to add to the continuing conversation about supply chain practices that are efficient, transparent, and sustainable as well as the application of blockchain technology from an engineering management standpoint.

It plays a pivotal role in shaping the subsequent discussions and insights presented in this thesis, laying the groundwork for a thorough exploration of the potential impact of blockchain technology on sustainable, transparent, and efficient supply chain management practices.

This chapter's research design will place special emphasis on the methodical process of finding, evaluating, and assessing a broad variety of academic sources, such as credible online databases, books, peer-reviewed publications, and conference proceedings.

To wrap things up, the methodology chapter is a crucial component of the research process since it provides a methodologically sound review of the literature and outlines the methodologically sound approach to conducting one.

2.4 Research design

The comprehensive literature review methodology, which is the primary means of gathering and assessing previously published scholarly articles, industry reports, and case studies about the application of blockchain technology to supply chain management, forms the basis of this study's overall research design. The necessity to create a solid theoretical and applied framework for comprehending the ramifications and intricacies of blockchain technology in the context of transparent, efficient, and sustainable supply chain management from an engineering management standpoint is the driving force behind this research design. (Wannenwetsch et al., 2023; Manzoor et al., 2022).

This study's literature review methodology is designed to address important research questions and hypotheses, specifically focusing on the impact of blockchain technology on supply chain transparency, sustainability, and efficiency. Numerous subjects are covered by the study questions, such as how to better integrate environmental, social, and economic factors into supply chain operations to support sustainability; how to address issues with data visibility, traceability, and risk management to improve transparency; how blockchain technology can help supply chain optimization achieve cost-effectiveness, responsiveness, and customer satisfaction; and how engineering management principles can help successfully integrate blockchain technology into supply chain management (Wannenwetsch et al., 2023; Dutta et al., 2020; Kshetri, 2021; Gurtu et al., 2019).

The research design's main objective is to advance knowledge and understanding in the field of sustainable supply chain management from an engineering management perspective by stressing the need for a rigorous and methodical approach when performing a literature review (Wannenwetsch et al., 2023; Gurtu et al., 2019; Liu B et al., 2022; Manzoor et al., 2022).

In conclusion, the necessity for a thorough and methodologically sound approach to conducting a review of literature, with the goal of advancing knowledge and understanding in the field of sustainable supply chain management from an engineering management perspective, explains why a literature review was selected as the research design. (Sánchez-Flores et al., 2020; Wannenwetsch et al., 2023; Panigrahi et al., 2019).

2.5 Data sources selection

The choice of data sources in a literature review methodology is essential to guaranteeing thorough coverage of pertinent literature. A methodical approach is used to identify the data sources by gathering academic publications, industry reports, and case studies that support the goals of the research. To guarantee the inclusion of relevant and high-quality materials in this study, certain criteria will be followed in the selection of data sources (Sheppard, 2020: Fink, 2019; Montecchi et al., 2021).

The process of identifying data sources will involve searching reputable academic databases such as PubMed, IEEEXplore, Science Direct, and Google Scholar. These databases will be systematically queried using relevant keywords such as "blockchain technology," "supply chain management," "sustainability," "transparency," "efficiency," and "engineering management." Additionally, the search will encompass peer-reviewed journals, conference proceedings, books, and reputable online repositories to capture a diverse range of literature.

In addition, recent publications will be given priority when choosing data sources to guarantee that the most recent developments and perspectives in the field are included. The inclusion criteria will also consider the relevance of the literature to the research topic, the credibility of the authors and publishers, and the alignment of the content with the study's focus on sustainable, transparent, and efficient supply chain management from an engineering management perspective (Montecchi et al., 2021; Wannenwetsch et al., 2023; Lim et al., 2021; Varsei, 2016).

It's crucial to remember that finding data sources will be an iterative process., involving the refinement of search queries (Gurtu et al., 2019) and the inclusion/exclusion of materials based on their relevance and contribution to the research objectives. The systematic approach to data source identification will ensure the comprehensive coverage of literature, enabling a thorough exploration of the potential impact of blockchain technology on supply chain management practices (Dutta et al., 2020).

In general, a strict and methodical approach will be used to select the data sources (Gurtu et al., 2019), with the goal of collecting a broad range of academic publications and business reports that offer insightful information about the application of blockchain technology to sustainable and efficient supply chain management (Dutta et al., 2020; Kshetri, 2021).

A literature review's inclusion and exclusion criteria are crucial for guaranteeing the choice of reliable, pertinent sources that support the goals of the study. The inclusion criteria for this study will give preference to academic publications, industry reports, and case studies that specifically address how blockchain technology can be integrated from an engineering management perspective to create sustainable, transparent, and efficient supply chain management. Inclusion criteria are the elements of a study that must be met in order for it to be included in the literature review, and the components of a study that rule it out for inclusion are known as exclusion criteria.

These standards, which establish the parameters for the literature review, are decided upon subsequent to the formulation of the research question. Study characteristics (e.g., PICOS, duration of follow-up), report characteristics (e.g., years considered, language, publication status), study types, sample size, sampling technique, and the presence of a pertinent comparison group in the study are a few examples of these.

To ensure that prejudice is not included in the final review, it is crucial to apply these criteria carefully. Typically, the inclusion and exclusion criteria information is documented in the form of a paragraph or table. It might also be required to provide definitions for specific concepts in the research question, along with the source of those definitions (McKenzie et al., 2016; Petticrew et al., 2008).

The rationale behind this criterion is to focus on literature that provides substantive insights into the theoretical and practical blockchain technology's consequences for supply chain optimization.

In a literature review, the inclusion criteria rank the articles according to certain requirements, and the exclusion criteria rule out studies. To capture the most recent developments and insights in the field, recent publications may be included as inclusion criteria for a literature review. The swift advancement of blockchain technology and its practical applications in supply chain management serve as justification for this approach, which guarantees that the literature review accurately reflects the current state of knowledge in this dynamic field (Glasziou et al., 2009; Rubin et al., 2012).

A literature review's exclusion criteria entail eliminating reputable or sources that do not support the main topic of the study. Outdated content that doesn't specifically address supply chain management's integration of blockchain technology, or does not have peer review validation will not be accepted. A literature review's inclusion and exclusion criteria are crucial for guaranteeing that the sources chosen are reliable and pertinent. These standards, which establish the parameters for the literature review, are decided upon subsequent to the formulation of the research question (Dickersin et al., 1994; Patino, 2018; Glasziou et al., 2009).

Using exclusion criteria in a literature review guarantees that reputable sources are excluded, as well as sources that do not support the main topic of the study. Content that lacks peer review validation, is outdated, or does not specifically address how blockchain technology is being incorporated into supply chain management will not be accepted. The literature review will uphold a high standard of relevance, credibility, and timeliness by putting these exclusion criteria into practice, which will support the study's scholarly integrity and methodological rigor (Rowley et al., 2004; Dickersin et al., 1994; Petticrew et al., 2008).
The inclusion and exclusion criteria aim to provide comprehensive coverage of the literature while preserving the high caliber and relevance of the sources that are included in the review.

Since a literature review is the main component of the research methodology, the specific techniques used to gather data will center around methodical and thorough processes for searching and reviewing existing literature. To compile the data for the literature review, the research will methodically search and retrieve academic publications, industry reports, case studies, and other pertinent materials from reliable academic databases and sources.

Furthermore, the data collection methods will prioritize recent publications to ensure that the field's most recent advances and insights are included. This method captures the current state

of knowledge in this quickly developing field while acknowledging the constantly changing nature of blockchain technology and its potential uses in the management of supply chains.

2.6 Data Collection Methods

A methodical and exacting approach will be used in the literature review to determine, gather, and compile high-quality sources to explore the impact of blockchain technology on transparent, sustainable, and efficient supply chain management practices.

Qualitative studies frequently employ techniques like observations, interviews, and document analysis to compile comprehensive, rich data. Through direct communication between participants and researchers, interviews enable the exploration of unique viewpoints, experiences, and insights pertaining to the research topic.

Observations involve the systematic recording of actions, connections, or phenomena in natural settings to collect data in real-time and develop a sophisticated understanding of social or organizational dynamics. Qualitative study data collection method must be chosen according to the question, goal, and nature of the subject phenomenon. By using appropriate data collection techniques, researchers can collect, analyze, and interpret data effectively to solve their queries and contribute to improving knowledge in their respective fields (Mazhar et al., 2021; Onwuegbuzie et al., 2016; Taherdoost, 2021; Paré et al., 2017).

2.7 Ethical Considerations

The ethical considerations in research, especially in the context of a literature review, are critical for maintaining the confidentiality, informed permission, and data protection of the sources used. In this study, ethical considerations were thoroughly incorporated into the research design.

The literature review methodology respects the intellectual property rights of the writers and organizations whose works are being reviewed. To ensure ethical utilization of sources, appropriate citation and referencing actions were used, with the materials' initial authors and contributors admitted. This approach complies with academic integrity standards and promotes transparency in acknowledging the intellectual contributions of others (Drolet et al., 2022; Kara, 2017; Thomas et al., 2015; Bhandari, 2021; Suri, 2019).

Any research project must take ethical conduct into consideration, but this is particularly pertinent when doing a literature review. Ethical principles guided the selection and inclusion of sources in the literature review, giving priority to high-quality and relevant sources. In order to protect against plagiarism and misrepresentation and to pay tribute to the original creators, proper citation and referencing techniques were used.

The study adhered to the highest standards of academic integrity and honesty, making sure that the combined data was appropriately presented and placed within the parameters of the literature review. The study aimed to further the academic conversation about using blockchain technology for sustainable, transparent, and efficient supply chain management from an academic perspective by maintaining ethical guidelines and standards and maintaining a high degree of integrity, transparency, and respect for the intellectual contributions of others (Drolet et al., 2022; Thomas et al., 2015; Suri, 2019; Bhandari, 2021; Kara, 2017).

2.8 Study Limitations

In any kind of study, it is critical to recognize and address the study's inherent limitations, as each of these variables can influence the understanding and generalizability of the results. Several limitations should be considered on the basis of this thesis's adoption of a literature review methodology (Ross et al., 2019; Labaree, 2013; Wordvice, 2022; Paré et al., 2017).

Primarily, there exists a possibility of publication bias due to the dependence on pre-existing scholarly works, industry reports, and case studies, since relevant literature may not always be readily available or accessible from one source or database to another. This limitation may affect the review's thoroughness, which could lead to an erroneous representation of the current state of the art. (Rasi et al., 2022; Haddaway, 2020; Wannenwetsch et al., 2023; Lim et al., 2021).

Second, the literature that was available at the time of the review might not have adequately covered the most recent advancements, new trends, or practical applications because supply chain management and blockchain technology are particularly dynamic fields. Consequently, the results may not fully represent the current situation of blockchain use cases for supply chain management so far. (Bischoff et al., 2021; Marengo et al., 2023; Wannenwetsch et al., 2023; Lim et al., 2021; Rasi et al., 2022).

Moreover, the extent of the literature review's purview may naturally restrict the in-depth examination of particular subtopics within the more expansive field of supply chain management and blockchain technology. This could mean that some subtle points or specific fields of study don't get enough attention, which could affect how much is learned from the review.

Additionally, it's critical to acknowledge the potential for interpretation bias when combining and evaluating data from various sources. Subjectivity may be introduced into the review process because qualitative evaluation is subjective and the possibility of varying perspectives among authors, which could impact the overall interpretation of the findings.

It is important to note that, while these constraints may limit the scope and depth of the literature review, they do not reduce the significance of the lessons obtained from the existing body of knowledge. By explicitly recognizing these limitations, the goal of the study is to present a critical and impartial evaluation of the body of existing literature., thus contributing to an in-depth comprehension of the integration of blockchain technology in sustainable, transparent, and efficient supply chain management from an engineering management perspective. (Wannenwetsch et al., 2023; Rasi et al., 2022; Lim et al., 2021; Marengo et al., 2023; Bischoff et al., 2021).

Summary

The chapter examines how blockchain technology might improve supply chain management's sustainability and transparency. It draws attention to supply chains' need for greater sustainability, efficiency, and transparency and emphasizes their safe and unchangeable distributed ledger technology. The research methodology is based on a literature review to critically assess existing knowledge, address research questions, and identify emerging trends. The study aims to contribute to the advancement of knowledge in sustainable supply chain management and engineering management.

The literature review methodology focuses on key research questions, such as the impact of blockchain technology on supply chain transparency, sustainability, and efficiency. The research design is qualitative, focusing on synthesis and analysis of existing scientific publications, industry reports, and case studies. Ethical considerations are paramount, with proper citation and referencing to respect the intellectual property rights of the original authors. The study maintains academic integrity and transparency, contributing to the scholarly discourse on blockchain technology for sustainable supply chain management.

The necessity of comprehending the intricacies and ramifications of blockchain technology in relation to sustainable supply chain management is emphasized throughout the chapter. It recognizes that there are limitations that could affect the review's thoroughness and accuracy, such as publication bias, the ever-changing nature of technology, and the possibility of interpretation bias. Notwithstanding these drawbacks, the chapter's goal is to offer a critical, fair, and comprehensive evaluation of the body of literature currently in circulation to advance knowledge of blockchain technology's application to transparent, sustainable, and efficient supply chain management.

3 Supply Chain

3.1 introduction

Incorporating blockchain technology into supply chain management can transform how businesses operate and interact with suppliers. Blockchain is a decentralized, distributed digital ledger that records transactions across multiple computers while maintaining transparency, security, and immutability. Utilizing blockchain technology can make supply chains more transparent, efficient, and sustainable, addressing today's most pressing business challenges. SCM, or supply chain management, is a crucial component of contemporary corporate operations, that involves the coordination and management of activities related to the production and delivery of products and services.

The supply chain is a network of organizations, people, activities, information, and resources that contribute to the creation and delivery of a product or service. The goal of Supply Chain Management is to create a sustainable competitive advantage while optimizing customer value. In today's globalized world, supply chains have grown in complexity, with several levels of distributors, manufacturers, suppliers, and retailers. Blockchain technology is already reshaping how we manage supply chains, with the possibility of creating safe and transparent networks.

It allows for quicker and more efficient product delivery, increases traceability, improves partner coordination, and facilitates access to financing (Gaur et al., 2020; Günthner, 2023). Blockchain technology can improve supply chain transparency and traceability while also lowering administrative costs and increasing overall efficiency. (Laaper et al., 2017; Richards, 2013).

Blockchain technology integration focuses on supply chain sustainability, transparency, and efficiency. Blockchain can help with supply chain sustainability by providing a transparent and secure infrastructure for tracking and verifying the provenance and legitimacy of products, lowering the risk of counterfeit products, and ensuring compliance with environmental and social standards (Gaur et al., 2020). By providing an unchangeable and impenetrable record of every transaction, it can increase supply chain transparency by allowing stakeholders to track the flow of goods and confirm the legitimacy of products. (Laaper et al., 2017).

Furthermore, Blockchain technology can increase the efficiency of the supply chain by automating a number of tasks. including tracking and verifying the genuineness of products, overseeing inventory, and providing secure and fast payments (Günthner, 2023; Queiroz et al., 2020). This chapter aims to provide detailed definitions of key supply chain concepts such as sustainable supply chain, efficient supply chain, and transparent supply chain.

It also addresses related concepts such as sustainability and traceability. To explain the role of the supply chain and related concepts, the discussion encompasses relevant academic citations in addition to real-world examples. This foundation is required for subsequent chapters, which will explore a detailed examination of how blockchain technology might affect supply chain management procedures.

3.2 Supply chain

This section looks at the growth of supply chain definitions through time. While these definitions have undergone minor changes, the overall concept of the supply chain has remained constant.

Here, we examine various expert and researcher perspectives on supply chain definitions to gain a thorough understanding of their conceptual development. (Fayez, 2005) believes that the supply chain is a complex network of interconnected businesses that collaborate to achieve particular targets. (Lambert, 2008) declares that It entails the efficient flow of information, materials, and products between organizations. From a logistics-focused approach to a more comprehensive one that incorporates a range of roles and activities, this idea has developed (Ballou et al., 2000; Stevens, 1990). (Tseng et al., 2019) expresses that The supply chain is a web of interconnected businesses, people, resources, and information that is used in the process of turning raw materials and natural resources into an end product that can be shipped to the customer.

The typical supply chain is transforming due to various factors such as hyper-segmentation, localization of product production and sources, Manufacturing 2.0, increased customer expectations, and end-to-end visibility for suppliers, customers, and companies. Large technology companies were prompted by these factors to start working together, which had an impact on the supply chain's entire process and boosted automation in an amalgamated architecture (Eze et al., 2019). To increase the effectiveness, agility, and dependability of the supply chain, a comprehensive strategy for combining the disparate manufacturing, purchasing, and ordering processes into a single platform was needed (Jabbar et al., 2021).

The supply chain network (SC network) is made up of suppliers, manufacturers, wholesalers, retailers, and customers (Madhani, 2016). According to (Ahi et al., 2016), it can also be defined as the web of connections between businesses, endeavors, groups, and technological systems that manages the demands of clients for goods, services, capital, or information in the form of pre- or post-manufacturing flows from suppliers to consumers.

A collection of value-adding operations conducted by multiple businesses with the goal of meeting the demands of the end customer is another definition of a supply chain. Of course, reaching the previous objective necessitates coordinating supply chain operations and logistical procedures with regard to informational materials, which include communication, technology, and human capabilities (Priyadarshi et al., 2021; Almatarneh et al., 2022).

A supply chain comprises a fundamental set of entities known as its members, including manufacturers, distributors in the shape of wholesalers and retailers, suppliers of materials and parts, and suppliers of logistics services (Hingley et al., 2015). However, incorporation and the achievement of the goals of the supply chain could be attained by carefully choosing the supply chain's participants and searching for the most cost-effective methods during chain operations. Additionally, incentives can be developed for suppliers who lower their prices for the facility to help it succeed in gaining an advantageous competitive edge in the Internet age. Corporate managers must embrace this vision for the facility to succeed in achieving a solid competitive edge (Wiengarten et al., 2016).

However, competition between entire supply chains now matters more than companies trying to give their all. Therefore, in order to be successful in an atmosphere of competition, the supply chain has grown in importance. Supply chain efficiency is raised by enhancing and meeting supply chain goals. Since the appropriate use of information technology promotes greater collaboration as well as coordination among the supply chain parties, it plays an essential part in incorporating the logistics processes that take place between the parties involved in the supply chain. Michael Porter's theories, which popularized the value chain model and emphasized the significance of integrating company procedures through a variety of logistical activities within the supply chain,

are responsible for the significance of integrating the interaction between the seller and the buyer within the supply chain (Al-Zaqeba et al., 2022). Some authors and researchers have referred to information technology as the foundation for developing and overseeing the supply chain because it can aid in achieving financial issues and strategic accomplishments in markets, particularly global markets (Boje et al., 2020). (Deraman et al., 2012) analysis of the relationship between information and communication and supply chain performance demonstrated the beneficial effects of interoperable information and communication systems.

The creation and maintenance of integrated relationships within the supply chain is facilitated by information, as noted by (Bakhtiarizadeh et al., 2019). This helps companies perform at their best, and (Singhry, 2015) also confirms this. Regarding the mandate that companies bolster their capabilities by emphasizing the advancement and maintenance of technological capabilities required to accomplish the integration of customers and suppliers throughout the supply chain.

Prior research has underlined the necessity of establishing cutting-edge information systems that can dissolve obstacles between buyers and sellers in order to guarantee that supply chain participants perform better (Al-Zaqeba et al., 2022). Information technology can be used to reduce shipping times, make information available when needed, provide accuracy, and enhance customer service, among other benefits within the supply chain. Enhanced energy efficiency, less paperwork, timely delivery, and higher productivity (Saberi et al., 2019). However, blockchain technology is one information technology that can be used to verify the integrity and accuracy of the data provided through it. Apart from the financial domain, it is highly beneficial in numerous other fields.

Blockchain technology is being applied to change a number of business domains, including finance markets, banking, supply chains, governance, health care, taxes, and smart government (Al-Zaqeba et al., 2022). Previous research, like that done by (Karajovic et al., 2019), has shown how applying blockchain technology to the supply chain can improve financial performance as well as operational performance, risk reduction, stock volume and ambiguity reduction, and sustainable development, in addition to its technical and technological advantages. Last but not least, any business that involves upstream and downstream activities between different organizational stakeholders across functional verticals must have a supply chain (SC). Its primary goal is to add value by providing goods and services in an effective and efficient manner.

3.3 Supply chain Management (SCM)

Supply chain management is a multifaceted, integrated program that requires the efficient flow of data, resources, and products between and among organizations (Lambert, 2008). It includes the procurement of materials, manufacturing, assemblage, and the transportation of goods or services to the customer (Borade, 2007). The idea is still developing and lacks a consensus definition (Wisner et al., 2000). Management of supply chains is essential for companies to improve customer service, achieve balance between costs and services, and gain competitive advantage (Stevens, 1990).

The entire supply chain system is largely driven by information technology (Misra et al., 2010). Monitoring vital business operations across the network of organizations is a crucial aspect of supply chain management. (Croxton et al., 2001). It is also necessary to consider the links, networks, and chains that comprise the supply chain. (Harland, 1996). (Aliyu et al., 2018) believe that the procedure of moving, storing, and delivering goods from the location of raw materials to

production and final customers is known as supply chain management. The development of blockchain technology has been closely observed by the logistics and supply chain management domains (Bialas et al., 2023).

In order to offer more value to customers for less money, supply chain management often entails managing and maintaining manufacturer relations with vendors, administration, and customers. The concept of the Internet of Things (IoT) offers innovative methods for tracking the movement of commodities and goods vital to supply chains by enabling the use of multiple intelligent actuators and sensors linked to the Internet (Viswanadham et al., 2023; Iranmanesh et al., 2023).

It focuses on the crucial component of supply chain management, which is the smooth sharing of product information amongst all parties engaged in its life cycle (Uddin et al., 2023). In supply chain management, monitoring vital business operations is a crucial aspect throughout the network of organizations (Croxton et al., 2001). It is imperative to take into account the interconnections, networks, and chains that comprise the supply chain (Harland, 1996).

3.4 Supply Chain Management Performance Drivers; Higher Efficiency and Effectiveness

SCM performance encompasses both effective and efficient operation management. Any attempt to increase supply chain efficiency is likely to be ineffective if effectiveness is not given the same priority. The efficiency and effectiveness of SCM performance is assessed, typically with reference to goals like cost, rapidity, dependability, excellence, and flexibility. Supply chain efficiency, a gauge of how well an organization's supply chain operations use its resources, is an internal performance standard. It gauges how successfully a company's supply chain uses the resources at its disposal to achieve cost-saving objectives.

An external measure of an organization's ability to satisfy the needs and expectations of the different supply chain stakeholders is its supply chain effectiveness. Greater efficacy in supply chain operations leads to improvements in service quality, while greater efficiency yields significant cost savings. Effectiveness refers to the extent to which a customer's expectations are fulfilled in the supply chain, whereas efficiency measures how cost-effectively the chain's resources are used to provide a predetermined level of customer satisfaction.

Enhanced productivity and efficacy in the supply chain generate income, cut expenses, boost profit, and eventually increase the value of the company (Madhani 2021). Objectives like quality, speed, dependability, cost, and adaptability are widely employed to gauge supply chain management effectiveness (Goldbach et al., 2003; Kovács, 2004; Meyer et al., 2000; Rao et al., 2005; White, 1996).

3.5 Supply chain sustainability

3.5.1 what is sustainability?

Sustainability as an idea has been the focus of exploration across various scientific disciplines for numerous years. Prior to delving into the examination of sustainability in relation to the supply

chain, this section aims to provide a comprehensive overview by reviewing the concept of sustainability and its related notions in a general sense. First, we will look at the definition of sustainability. Sustainability is a multifaceted and intricate concept that includes the imperative to meet current needs without jeopardizing future generations' ability to do the same (Church et al., 2022; Kuhlman et al., 2010).

It entails the sustainable use of biophysical environments (Hueting et al., 1998), as well as the integration of ecological, social, economic, and technological perspectives (Cabezas et al., 2004). Over time, the idea has expanded to include social, economic, and environmental well-being dimensions (Kuhlman et al., 2010), as well as indicators, scenarios, goals, and targets (Kates, 2015). Nonetheless, there is a need for a formalized and operationalized definition of sustainability (Heal, 1998), as well as a call to establish it as a consistent, standardized practice across various fields of work (Mitra, 2010). (Elkington et al., 1999), (Kajikawa, 2008), (Schoolman et al., 2012), and others have shown that sustainable performance, as it relates to the theory of sustainability, may encompass the three sets of criteria that are concerning the environmental, social, and financial aspects of sustainability.

Thus, from the standpoint of sustainable performance, social, financial, environmental, and economic factors can occasionally clash (Boons et al., 2009; Spreitzer et al., 2012). The World Commission on Environment and Development first discussed the idea of sustainability in 1987. ("Report of the World Commission on Environment and Development: Our common future." 1987) Over the next few decades, it has expanded to about 300 definitions (Johnston et al., 2007). According to economist Robert Solow, the 1987 winner of the Nobel Prize in Economics, sustainability is about giving the next generation "the capacity to be as well off as we are today."(Solow, 1991). In keeping with this way of thinking, the United Nations (UN) presented the most comprehensive and extensively used definition of sustainability in 2005.

The UN defined sustainability as having three main pillars: environmental, social, and economic sustainability. The use of resources, energy efficiency, waste production, and emissions from commercial operations are the primary standards for environmental sustainability (Sarkis, 2003; Saberi et al., 2019). The main concerns of social equity are a number of human rights-related issues, including child labor, racial or gender wage disparities, diversity and equal opportunity, and workplace health and safety (Venkatesh et al., 2020).

The long-term profitability and success of the business are correlated with the governance performance. Morgan Stanley Capital International's 2019 ESG rating methodology report, also addresses internal business matters, such as stakeholder communication (MSCI ESG Research, 2019). Businesses have widely discussed and implemented this ESG assessment guidelines to demonstrate their sustainable performance and engagement (Tanin et al., 2019; Zeidan et al., 2015).

Social sustainability is concerned with how businesses affect employees, clients, and even surrounding communities in order to maintain a healthy society. (Mani et al., 2014; Hutchins et al., 2008). When an econof can grow steadily without compromising social and environmental sustainability, it is said to be in a sustainable state. The governance concept is frequently used to refer to the economic sustainability pillar in the context of supply chain and corporate management.

For the business to be guaranteed transparency, traceability, and accountability, a robust management structure must be established. This will help to improve relationships with external

stakeholders and draw in new investors (Seuring et al., 2008; Nayak et al., 2019). Corporate behavior and corporate governance are the two main themes that influence sustainable governance. The former theme is represented by board activities, ownership, and accountability, according to MSCI ESG Research (2019).

3.5.2 Sustainability in supply chain

Following the examination of sustainability concepts in the preceding section, the subsequent part is dedicated to discussing sustainability within the supply chain and its associated concepts. This section aims to provide a comprehensive overview of sustainability within the supply chain, encompassing the characteristics of a sustainable supply chain, the advantages associated with such a framework, and the challenges impeding the sustainability of a supply chain.

Supply chain sustainability is the integration of economic, environmental, and social factors when obtaining raw materials, converting them into products, and distributing them to consumers (Duan et al., 2022). Visibility and the extent of information disclosure are the two components of supply chain transparency (Mol, 2015). Retailers' sustainability policies in logistics were examined by (Quak et al., 2007), who concentrated on social and environmental problems like carbon dioxide emissions, traffic jams, and noise pollution. Previous studies have also contended that supply chain sustainability-related problems, which frequently involve environmental and social issues, are less quantitative (Linton et al., 2007).

Supply chain sustainability is the process of managing a supply chain to reduce its negative impacts on the environment and society. This can be accomplished through employing sustainable materials and practices, eliminating waste, and increasing efficiency (Munir et al., 2022). According to (Seuring et al., 2008), sustainability is defined by the triple-bottom-line concept, which balances the social, environmental, and commercial aspects of supply chain management.

Confirming and verifying that the activities, products, and processes in the supply chain satisfy specific sustainability certifications and criteria is a crucial strategic and competitive challenge for sustainability in supply chains (Grimm et al., 2016).

These challenges boost concerns about whether the information systems in place for the supply chain can securely support the data needed to determine the provenance of goods and services in a timely manner and in a way that is reliable and transparent. The enhancement of supply chain transparency, security, durability, and process integrity holds the key to solving these intricate issues. It's possible that blockchain technology will solve this issue. These improvement goals are now more organizationally, technologically, and financially feasible thanks to new technological advancements and applications utilizing the blockchain concept (Swan, 2015; Abeyratne et al., 2016).

3.5.3 Sustainable Supply Chain Management (SSCM)

According to (Gold et al., 2010), (Alvarez-Gil et al., 2007), (Beske, 2012), and (Beske et al., 2014), the existence of three essential components social, environmental, and financial for product manufacturing can be described as the fundamental concept of sustainability. According to (Khan et al., 2017), SSCM is related to the management of materials and waste reduction from upstream to downstream.

It also explicitly considers the enhancement of the environmental and social impact after shelving life back upstream (Siong et al., 2011). " SSCM is the process of incorporating sustainability into traditional supply chain management procedures while accounting for the social, economic, and environmental effects of company operations." (Altuntas et al., 2014).

"SSCM is an addition of social and environmental aspects to the existing SCM ideology." (Wittstruck et al., 2012). Applications of sustainable supply chain management are seen in the following industries: manufacturing (Khan and et al., 2017; Eskandarpour et al., 2015), healthcare (Hasini et al., 2012), education (Zhu et al., 2006), construction (Dadhich et al., 2015), services (Ayuso et al., 2013), and finance (Ageron et al., 2012).

Reducing fossil fuel and electricity consumption, as well as having environmentally friendly disposal properties, are prerequisites for the firms to implement environmentally friendly procedures in their SC (supply chain) operations in order to sustain the upcoming platform of business (Khan et al., 2019b; Abdallah et al., 2012). In supply chain management, sustainability has grown in significance over the last several years. Emerging technologies such as blockchain hold the potential to facilitate businesses striving to enhance their social responsibility, reduce their environmental footprint, and augment transparency (Daghighi et al., 2023).

"The management of material, information, and capital flows as well as cooperation among companies along the supply chain while taking goals from all three dimensions of sustainable development, i.e., economic, environmental, and social, into account which is derived from customer and stakeholder requirements" is how (Seuring et al., 2008) define sustainable supply chain management. (Elkington, 1998) proposes that the three sustainability dimensions require a balanced focus, a concept known as the "triple bottom line.". While consumers frequently concentrate on the environmental aspects of sustainability, supply chain sustainability involves a more comprehensive approach that takes into consideration social and economic factors all along the value chain of a final product.

Supply chain sustainability takes an integrated approach to ensure reliable management of incoming and outgoing procedures as well as logistics within a supply chain from a social, environmental, and economic perspective. Because there isn't a single, widely-accepted model for gauging sustainability within a heterogeneous global economic network, sustainability standards have grown contentious. The global supply chain's sustainability is gaining a lot of attention because more than 93% of the 250 biggest companies in the world report on it (Park et al., 2021).

Another issue that is becoming more and more of a worry is the global supply chain's disability to define and obtain sustainability-related data. As a result, a strategy for guaranteeing a sustainable supply chain must first carefully take into thought the accurate identification of quantifiable characteristics, which can vary depending on the supply chain. After being identified, characteristics must be grouped according to the main sustainability dimensions. Three performance dimensions economic, environmental, and social are realized concurrently in the sustainability literature, according to various definitions offered by academics and professional associations (Sánchez-Flores et al., 2020).

The triple-bottom-line (TBL) principle, which views a sustainable organization as an entity where the sustainability evaluation process extends beyond traditional and economic issues, complies with the three dimensions (Njualem et al., 2021). Strict evaluation criteria that take into account the social, environmental, and economic aspects are required. Given this all-encompassing

viewpoint on supply chain sustainability, a thorough definition of the concept is crucial. To satisfy the needs of stakeholders and improve the organization's resiliency, profitability, and competitiveness over the long run, (Ahi et al., 2013) defined sustainable supply chain management (SSCM) as "the development of coordinated supply chains through the voluntary integration of economic, environmental, and social determinants with key inter-organizational business systems created to efficiently and effectively oversee the material, information, and capital flows associated with procurement, production, and distribution of products or services."

Good governance practices are also necessary for supply chain sustainability through the life cycle of goods and services. As a result, SSCM and SCS are complementary. The integration of supply chain visibility, to create an integrative route regarding sustainable supply chain visibility is made easier by the definitions' overall context. The concept of sustainable supply chain visibility expands upon traditional supply chain visibility by incorporating the supply chain's social, environmental, and economic goals (Sunmola, 2021).

3.5.4 characteristics of a sustainable supply chain

Subsequent to the analysis of sustainability within the supply chain and its associated concepts, this section will provide a concise overview of the characteristics inherent in a sustainable supply chain.

A supply chain that actively manages its social, environmental, and economic components is said to be sustainable (Bouchery et al., 2017). It entails integrating social and environmental requirements with stakeholder concerns (Flores-Sigüenza et al., 2021) and taking environmental factors into account at every supply chain stage (Arora et al., 2015). Increased sales, lower expenses, less financial risk, and eventually more stock valuations are all possible outcomes of this strategy (Mefford, 2011). But it also poses particular difficulties for global supply chains, necessitating particular arrangements and oversight procedures (Koberg et al., 2019). According to (Zhang et al., 2014), optimizing a sustainable supply chain entails taking the supply chain as a whole into account, using the right sustainability indicators, and evaluating the effects on the economy, the environment, and society.

According to (Barbara-Póvoa, 2009), two important obstacles to sustainable supply chains are the requirement for a methodical approach and the long-term success to be taken into account. A sustainable supply chain is a complex system that necessitates a multifaceted approach to balancing economic, environmental, and social considerations. Given the complexity, unpredictability, and subjectivity of the process, decision support that assists with decision-making is critical (Taheri-Moghadam et al., 2019; Mota et al., 2015).

A crucial component of forward supply chain design and management is the incorporation of sustainability indicators. It is stressed how important it is to have a comprehensive framework for optimizing sustainability that takes social, economic, and environmental goals into account (Flores-Sigüenza et al., 2021; Kannegiesser et al., 2014). It is stressed how important it is to consider sustainability at every stage of the supply chain. It also emphasizes the significance of life cycle assessment concepts in the design of sustainable supply chains. The last suggestion is to turn sustainability issues into a competitive advantage and source of value (Linton et al., 2007; Chaabane et al., 2012; Darmanata et al., 2010).

Configurations and governance mechanisms are essential components of sustainable supply chain management, and they are especially crucial in global supply chains. (Koberg et al., 2019). The problems of system-wide integration, indicator selection, and sustainability assessment can all be addressed with the aid of a multi-objective optimization framework (Zhang et al., 2014). Industry supply chains can benefit from the application of a comprehensive framework for sustainability optimization that takes social, economic, and environmental goals into account (Kannegiesser et al., 2014).

A growing trend in supply chain management is the integration of sustainability, which is motivated by the need to decrease costs, abide by laws, and gain a competitive advantage (Ansari et al., 2015). There is a recommended approach for supply chain design that takes sustainability factors like carbon emissions and logistics costs into consideration. It is also essential to create a green supply chain, which aims to achieve sustainable development and lessen its impact on the environment (Chaabane et al., 2011; Lam et al., 2015).

3.5.5 Benefits and advantages of a sustainable supply chain

In this section, we succinctly outline several advantages and benefits associated with a sustainable supply chain.

Creating a sustainable supply chain has many advantages, such as lower costs, enhanced brand recognition, and the opening up of new business prospects (Logožar, 2023; Chakravarty, 2014). Moreover, it may result in higher profits, lower expenses, lower financial risk, and more sales. Environmental, social, and economic performance can all be improved by incorporating sustainable policies and practices into the supply chain. It is a difficult and demanding task to create a supply chain that is truly sustainable (Aytekin et al., 2022; Pagell et al., 2017).

Greater economic and environmental performance can result from the adoption of sustainable supply chain networks, which can assist in resolving conflicts between ecological and economic goals. The supply chain must work together and with excellent management in order to incorporate sustainability. The trend of incorporating sustainability into supply chain management is growing despite the obstacles (Winkler, 2010; Sembiring et al., 2019; Ansari et al., 2015).

3.5.6 Challenges and Obstacles in Achieving Sustainability within the Supply Chain

The integration of sustainability into supply chain processes is a complex task, with several key drivers and obstacles. (Alzawawi, 2014) identifies drivers such as environmental concerns and governmental regulations, while (Zhang et al., 2014) emphasizes the need for multi-objective optimization to balance economic, environmental, and social impacts. (Tay et al., 2015) and (Ansari et al., 2015) both highlight the importance of organizational factors, with the former discussing barriers and drivers, and the latter focusing on the challenges of incorporating sustainability into existing supply chains.

(Fransoo et al., 2014) and (Fiksel, 2013) both stress the need for a multi-objective approach to balance economic and environmental performance, with Fiksel specifically calling for a shift to a sustainable global economy. (Kumar et al. 2021) and (Logožar, 2023) further explore the challenges and opportunities of sustainable supply chain management, with Kumar focusing on

the barriers in the era of Industry 4.0 and the circular economy, and Logožar discussing the advantages and challenges of developing a sustainable supply chain.

The implementation of sustainable supply chain practices presents challenges for the pharmaceutical industry specifically, such as the requirement for a skilled workforce and effective legislation. Despite these obstacles, the food industry has the chance to promote healthier eating habits and make investments in environmentally friendly production and distribution methods (Melati et al. 2021; Smith, 2008). To overcome these obstacles and pinpoint the most important concerns in sustainable supply chain management, additional research is required (Barbosa-Póvoa, 2009).

3.6 Supply Chain Transparency

3.6.1 Transparency in Supply Chain

In this section, we will comprehensively review a variety of scholarly articles, books, and other academic resources to gain a thorough overview of transparency, particularly within the supply chain context. Our exploration will encompass an overview of transparency, its relevance within the supply chain, the defining characteristics of a transparent supply chain, and associated conceptual frameworks.

Transparency in the supply chain is the disclosure of information to regulators, trading partners, shareholders, and consumers. It records high-level data along the supply chain, including the names of suppliers, the various locations involved, components of the product, and related certifications. Based on the earlier definitions, we deduce that traceability is a necessary condition for the realization of transparency. Opportunities to assess the efficiency of supply chains, comply with legal requirements, and substantiate sustainability claims are presented by traceability.

To accomplish traceability and a high degree of transparency, many contemporary supply chain projects employ an alternative technical approach. Independent partners that each represent a separate, centralized system make up the supply chain. Consequently, a lack of trust between the partners could undermine data transparency and necessitate the development of more robust trust (Zorzini et al., 2015; Grimm et al., 2016).

Customers can also ask for information about the products, such as the place of manufacture, the caliber of the service, and safety certification. Encouraging transparency at every stage of the supply chain enables consumers and businesses to track the origin of their goods, thereby fostering trust. This can be accomplished with the use of Internet of Things (IoT)-connected technology. (Dey et al., 2018; Li, 2018). Supply chain traceability and performance are enhanced by the Internet of Things technology used to deliver the data over the network. However, extra data loads within the separate systems of the partners impose constraints on the supply chain.

Stakeholder participation, sustainable supply chain information, and perspective are all included in the broad definition of transparency in supply chain management (Schäfer, 2023). It entails using technology to make product information available to managers and customers, such as RFID tags and online databases.

According to (Abeyratne et al., 2016; Chen et al., 2018; Francisco et al., 2018), there are three components to sustainable supply chain transparency:(I) The spectrum of transparency, encompassing elements like the extent of supply chain partner participation, the range of

activities, and environmental and social data; (II) Product transparency, encompassing the tracking of product components (like the origins of raw materials), the tracking of product processes (from the point of origin to the final consumer), and the tracking of product sustainability data (like carbon emissions and recycling); and (III) Participant transparency, featuring visible participant operations, situational information, and sustainability conditions.

Divergent opinions exist on the meaning of transparency, according to (Hofstede et al., 2004) the degree to which supply chain participants are in agreement and have unimpeded access to information about products and processes without loss, noise, delay, or distortion is known as supply chain transparency and (Lee et al., 2021) believe that traceability and visibility are closely related to transparency. The scope of transparency has been defined in a variety of ways.

Business transparency is the provision of full, timely, and accurate information; it also promotes stakeholder honesty, enhances teamwork, and facilitates group decision-making. Accurate information about operations, procedures, and products including their sourcing and origin, processing techniques, and logistics is shared through supply chain transparency. Process transparency is the term used to describe the organizational policies that guarantee that information is accessible, useful, comprehensible, and presented to all stakeholders (Sánchez-Hernández, 2019; Jiang et al., 2022).

The capacity to retrieve and modify data with speed, independent of its location or the application that created it, is known as data transparency (Menon et al., 2021).

3.6.2 The Interplay of Supply Chain Transparency with Traceability and Visibility

It has been discussed that visibility and traceability help to create transparency. (Lee et al., 2021). Businesses must first make investments in supply chain visibility as a prerequisite for supply chain transparency. They need to lay out their supply chain processes first. After that, they must complete commissioning reports, supplier interviews, and audits. The financial benefit of this supply chain visibility investment comes from better operational decision-making. The needs of internal stakeholders in the business (or its supply chain), such as managers, direct suppliers, or customers, are met by visibility.

Transparency, on the other hand, focuses on a larger range of external stakeholders, such as investors, monitoring organizations, consumer rights advocacy groups, and NGOs (Handfield, 2016). By making publicly available data regarding a product's attributes, its origin's location, its movements, ownership, and its processes available, traceability promotes transparency (Vivaldini, 2020) and is something that supply chain participants should take into account. It's also important to note that supply chain processes may be considerably more transparent thanks to traceability systems (Sunny et al., 2020).

(Rao et al., 2021) stated that “Transparency in the supply chain is said to have its origin in supply chain visibility”. Enhancing data accuracy in blockchain-based transparency systems requires visibility, which concentrates on particular supply chain processes and outcomes like sustainability performance and information sharing. Increasing trust is one of the most significant applications of blockchain technology, and transparency is probably a prerequisite for trust. Blockchain also offers a trustless approach by using techniques like smart contracts to eliminate

the demand for intermediaries in the supply chain (Lee et al., 2021; Bai et al., 2022; Bai et al., 2020).

Reduced expenses and cost savings have been viewed as crucial success factors for ensuring the development and maintenance of transparency systems. By allowing information to be freely shared throughout the supply chain, transparency can reduce costs. It can also help to improve forecasts and inventory levels, which will improve performance (Mann et al., 2018; Tayal et al., 2021).

Blockchain protects supply chain partners' and focal firms' privacy while facilitating visibility and transparency in supply chain transactions (Bai et al., 2020; Liu et al., 2020; Queiroz et al., 2021) thus making a substantial contribution to sustainable supply chain management (Tian et al., 2021). Companies benefit from decision-support platforms that use machine learning techniques to create predictive algorithms with insights to lower the carbon footprint of SC operations. Blockchain technology can be integrated with these systems to ensure traceability and transparency among SC partners across industries. (Tsolakis et al., 2021; Tang et al., 2019).

3.6.3 Interconnection of Supply Chain Transparency and Sustainability

Transparency in supply chains and sustainability are related in a number of ways. First, the supply chain's sustainability may be enhanced by its transparency. For instance, businesses can more readily adopt procedures based on transparent information to satisfy stakeholders' long-term needs and foster confidence (Duan et al., 2022). Second, in order to be sustainable, businesses must act responsibly and transparently and submit to public scrutiny (Wamba et al., 2020). For example, in order to meet legal obligations and acknowledge the supervision of external personnel, businesses must disclose sustainability information.

Third, suppliers' sustainable performance can be greatly enhanced by supply chain transparency (Gardner et al., 2019). To increase supply chain sustainability, companies like Apple and Nike, for instance, use supply chain transparency by voluntarily releasing the list of suppliers to the public (Chen et al., 2019). Businesses such as Walmart have discovered the benefits of BCT-enabled food product traceability, particularly for wheat and soybeans.

They can proactively carry out safety inspections and track down the origin of tainted goods (Gligor et al., 2022; Kshetri, 2018). There's no agreement on how to make the supply chain sustainable and transparent (Schmidt et al., 2019), Disruptive and emerging technologies, however, offer a potent potential means or instrument.

Big data analytics, blockchain, the Cloud, and the Internet of Things (IoT) are some of these disruptive technologies (Stergiou et al., 2020; Effah et al., 2021). Blockchain technology has emerged as a potentially essential tool for businesses to manage the risks and complexity of increasingly complex global supply chains. Additionally, it can offer the required transparency to satisfy stakeholders' demands for a sustainable supply chain.

3.6.4 Procedures of Supply Chain Transparency

The current global supply chain is made up of a complicated web of industry-spanning stakeholders who work together to coordinate tasks and reach agreements. The key supply chain obstacles are shown in Figure 3. and include centralized systems, a lack of transparency, scalability issues, difficulties integrating IoT, and emerging technologies.

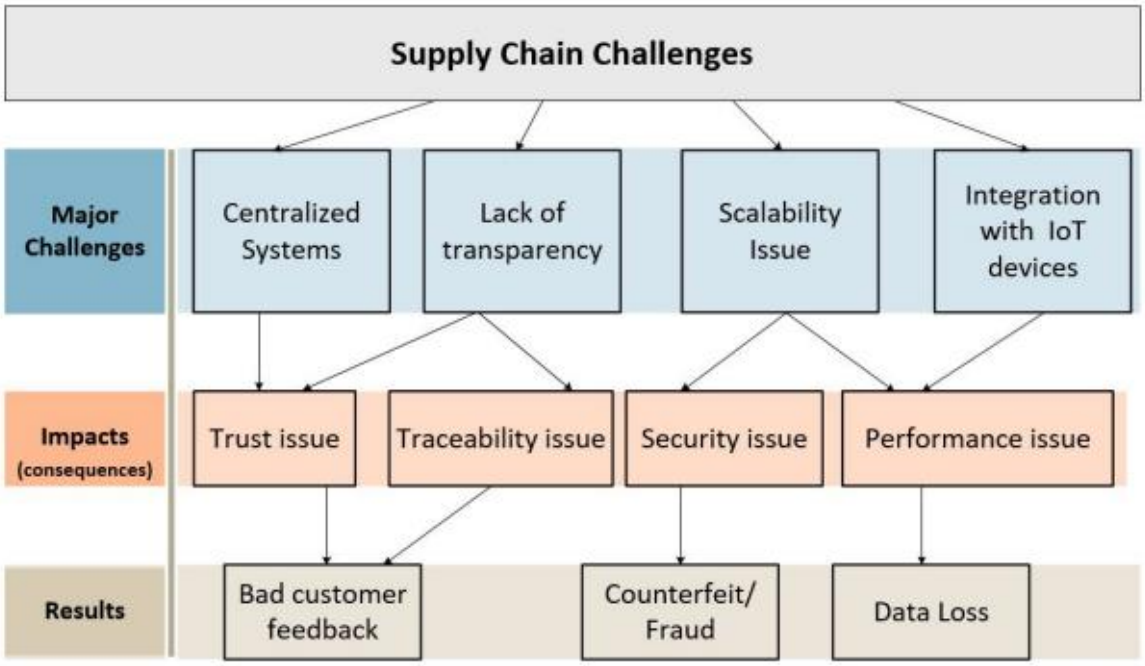

Figure 3. Technical Supply Chain Challenges. (Hellani et al., 2021)

The current centralized supply chain systems employ trusted third parties and workarounds to ineffectively provide some of the essential requirements (Rejeb et al., 2019) along with the excellent incorporation of new technologies.

These independent databases suffer from a lack of trust, which has led to unsatisfied and negative customer reviews. The primary transparency problem with a centralized system is that most of the supply chain lacks trustworthy shared information. Negative customer feedback, trust issues, and traceability are all caused by a lack of transparency. Furthermore, when the product is used in multiple geographical locations, scalability becomes a significant issue. It includes important documents like invoices, customs paperwork, ISO certificates, letters, proofs, and so on, and necessitates hundreds of conversations between parties. According to a study, 200 communication processes are required to deliver a single product (Haswell et al., 2017).

Consequently, scalability issues lead to performance and security issues. As a result, these lead to data loss and, frequently, counterfeits in the intended product data. Customers may become dissatisfied as a result, and partners may develop trust issues. Furthermore, the centralized conditions of the present network framework prevent it from fully utilizing IoT and from managing and analyzing the vast amounts of incoming data (Rejeb et al., 2019). This eliminates a significant amount of the power of the Internet of Things. Presently, there exist untrustworthy structures and networks intended to link billions of diverse and heterologous Internet of Things devices and the services they offer, along with data collection and analysis (Manyika et al., 2015).

3.6.5 Challenges and Hurdles in Attaining Supply Chain Transparency

Numerous studies have demonstrated how difficult and diverse it is to achieve supply chain transparency. The six main areas of focus identified by (Montecci et al., 2021) are traceability, sustainability, governance, knowledge integration, transparency technologies, and resilience. However, the implementation of these areas is not without its challenges. (Hellani et al., 2021) and (Steinfield et al., 2011) both emphasize the need for a balance between data transparency and process opacity, with the latter proposing the use of hub-type information technology architectures.

(Astill et al., 2019) further underscore the importance of information exchange and the use of enabling technologies, such as the Internet of Things and blockchain, in achieving transparency. The importance of social sustainability and the requirement for a system architecture that combines blockchain, IoT, and big data analytics are highlighted by (Venkatesh et al., 2020). (Bhagavan et al., 2021) takes things a step further by presenting a decentralized distributed application architecture that utilizes smart contracts and blockchain technology for supply chain procurement and cloud asset deployment. The aforementioned studies emphasize the significance of tackling the obstacles related to supply chain transparency and the potential of technology, specifically Blockchain, to surmount them.

3.6.6 Attributes, Key Components, and Principal Specifications of a Transparent Supply Chain

Having thoroughly examined various perspectives on transparency and its application within the supply chain, this final section titled "Transparency" will provide a concise yet comprehensive overview of the defining attributes and features of a transparent supply chain.

Transparent supply chains are characterized by transparency, accountability and open communication (Douglas, 2009; Gunasekaran et al., 2004). Dimensions like comprehensiveness, regularity, timeliness, content, scope, and user-friendliness are taken into consideration when evaluating it. To optimize operations and make business decisions, this transparency is essential (Ada et al., 2021; Gunasekaran et al., 2004). Technology, such as online databases and radio frequency identification tags, can be used to accomplish it. Technology has been the driving force behind the evolution of supply chain transparency, with an emphasis on ethical production and sourcing (Hasan et al., 2023).

In order to guarantee food quality and provenance, a transparent supply chain is essential. This can be accomplished through information sharing, standards for safety and quality, and governance procedures. Content, its scope, and comprehensiveness are three essential components of transparency that can be improved with the use of technologies like online databases and radio frequency identification tags (Montecchi et al., 2021; Ada et al., 2021; Trienekens et al., 2012). (Meier et al., 2008) puts forth a concept for creating transparent supply chains, but (Schäfer, 2022) stresses the importance of having a precise definition and framework especially when it comes to sustainability.

In evaluating transparency, (Godar et al., 2016) proposes a middle-ground strategy that strikes a balance between scale and detail, and (Steinfield et al., 2011) emphasizes the significance of shared information technology architectures, data and process standards, and both. Finally, Enhanced consumer trust and marketing advantages (New, 2010), lower operating costs (Chod et al., 2020), and better governance and complexity control (Meier et al., 2008) are just a few advantages of having a transparent supply chain. Additionally, it improves sustainability, especially in conjunction with NGO oversight (Chen et al., 2019). However, businesses frequently find supply chain transparency to be expensive and difficult to implement (Sodhi et al., 2019).

3.7 Supply Chain Efficiency

3.7.1 Efficiency versus Effectiveness

An organization can gain a competitive edge over its rivals by offering value to its customers in two ways: either by outperforming competitors in terms of cost or by outperforming them in terms of greater differentiation (i.e., by carrying out activities in a unique and efficient manner). It is ideal for supply chain strategies to reach high levels of efficacy and efficiency. Effectiveness is doing the right things, and efficiency is doing things correctly. As a result, performance measurement examines both efficacy and efficiency in completing a task. Efficiency, which is computed as the normal levels of inputs divided by the real levels of outputs, is the ratio of resources used to results obtained. Effectiveness is the ratio of real or actual outputs to normal or expected outputs, and it characterizes the degree to which an organization achieves its goals (Sodhi et al., 2017).

3.7.2 Enhancing Supply Chain Efficiency (SCE)

The notion of supply chain management surfaced, to maximize operations throughout the value chain and synchronize resources to secure a competitive edge. In addition to other business processes (such as managing stock, logistics, storage, ordering, customer relationship management, demand management, order fulfillment, and buying goods, etc.), this concept encompasses every link in the value chain. With a focus on supply chain operations, this concept also adopts a holistic methodology for managing relationships and operations amongst the players in the supply chain (Madhani, 2016).

Enhancing productivity, decreasing downtime, reducing inventory, developing market share, and externalizing the supply chain process are the goals of supply chain management. This practice boosts the performance of the company and maintains a company's competitive edge (Chin et al., 2015). The general objectives of the supply chain are to: provide local or global competitive advantages; create a connection between customer needs and supply chain activities; deliver high-quality products and services at the appropriate time and price; and lower costs across the supply chain by means of efficient alliance management and better relationships among chain participants (Tian et al., 2022). Three fundamental aspects of supply chain performance are being measured by research trends, and these are: raising customer satisfaction, lowering expenses, and enhancing responsiveness among supply chain participants (Yadav et al., 2022).

However, some research has added further factors that are required to assess the effectiveness of the supply chain. These factors include the company's market performance, which is indicated

by its market share, and its financial results, which is indicated by its profits and yearly earnings volume (Mouzas et al., 2022). A number of studies have identified the specific dimensions of supply chain efficiency, including lower manufacturing costs, lower total costs, lower inventory costs, faster response times to customer requests, higher customer service standards, lower stock out rates, increased market share, higher growth rates, and higher sales volume (Singhry, 2015). Many issues affect the supply chain's efficiency and consequently drive up costs.

The biggest problems are with ineffective inventory control and costly, time-consuming letters of guarantee, the difficulty in determining who is responsible for theft and fraud, customer dissatisfaction, the difficulty in following up on defective goods promptly, the difficulty of relying on customs brokers to avoid fines, and the issue of inefficient product routing and shipping that raises shipping costs (Pinheiro et al., 2018). Because it cultivates a sense of trust between the facility, customers, suppliers, and all other parties, blockchain technology which has the unique qualities of verification, sharing, traceability, and programmability helps to increase the efficacy and efficiency of the supply chain.

Every transaction made by any party is kept on file in the form of blocks that are instantly authorized and verified. Blockchain technology also helps with the integration of customer data, including their preferences, whereabouts, and complaints, as well as the efficient handling of customer complaints and frequent customer surveys. Enhancing the rapport with suppliers is another benefit as it guarantees the supply of production inputs that meet the necessary standards for costs, quality, and quantity.

Additionally, blockchain technology provides continuity of information flow for the management of origin between departments and both quantitatively and qualitatively between the supply chain's two sides. This helps to manage reverse flows, which include product damage and sales returns, and works to reduce these flows. Additionally, it helps with timely information sharing and exchange, which lowers the cost of goods while also satisfying consumer demands and decreasing uncertainty. Lastly, Blockchain reduces the duration of a product's life cycle, enhances inventory control, which lowers spoilage costs, and decreases the cost of producing a product by enhancing collaboration with facility departments (Wang et al., 2020; Rejeb et al., 2019; Behnke et al., 2020).

3.7.3 Implications of Supply Chain Efficiency and its Effects

As specialization and decentralization have grown, producers and retailers have had to adapt to work in progressively more complex environments. The length of supply chains from suppliers of raw materials to merchants is further increased by globalization, leading to a variety of inefficiencies in the chain, such as excess work-in-process, inventory, shortages, lengthy transit times, and unpredictable production quantities because of disruptions or random yields (Wurst, 2019). Significant negative effects have resulted from these inefficiencies, such as poor customer experiences and increased operating expenses for the company. For instance, it's estimated that supply chain inefficiencies cost the UK roughly $2 billion (Lopez 2018) and India $65 billion (Cornish 2020).

Unexpected worldwide chip shortages in 2021 severely disrupted production and resulted in significant financial losses for the automobile industry. With contract design and optimization, academics and industry professionals have significantly improved supply chain efficiency.

Mechanisms for achieving the best supply chain earnings in decentralized firm decisions, or supply chain coordination, have proven to be highly effective in a variety of settings. Coordination becomes challenging, though, when several companies are involved, either on the upstream or downstream sides of the channel.

One of the main causes of this issue is the supply chain's visibility, as companies may be reluctant or unable to provide verifiable information about their operational details. In this paper, we present a method that makes use of the recently developed blockchain technology to perform supply chain coordination involving multiple suppliers. Although supply chain optimization is thought to be a key growth area, blockchain technology has since surpassed its origins and found a diverse range of operational applications, including financial applications like payments and cryptocurrencies (Nakamoto 2008; Deloitte 2020). Transparency and data immutability are two of the main characteristics of blockchains. Put differently, blockchains facilitate the timely and verifiable sharing of operations data, including production and inventory information, among supply chain participants. The supply chain's decision-making process depends on the availability of accurate data. Crucially, the blockchain architecture makes it possible to write "smart contracts" using data from the blockchain, which can significantly increase the range of viable agreements between supply chain participants.

In the context of enterprise blockchain applications, permissioned blockchains like the Walmart-IBM food safety blockchain must be used by authorized parties due to business considerations. This is in contrast to public or permissionless blockchains, like Bitcoin or Ethereum, which can be operated by anybody. Permissioned blockchains offer a distributed, decentralized solution with better security and performance while preserving the immutability of data. In forthcoming chapters, an extensive exploration of blockchain and its variants will be undertaken. This inquiry will encompass nuanced analyses of blockchain's conceptual frameworks, technological advancements, and diverse applications across industry.

3.7.4 Efficient supply chain management

Businesses, especially SMEs, must prioritize efficient supply chain management because it has a direct impact on customer satisfaction, cost savings, and competitiveness (Kot, 2018; Atnafu et al, 2018). decreased delivery times, fewer operational inefficiencies, and increased overall productivity are the results of optimized supply chains (Moons et al., 2019; Kumar et al., 2022). The scientific publications at present emphasize how blockchain technology can improve a company's financial stability, export performance, and supply chain efficiency. (Dal Mas et al., 2023; Natanelov et al., 2022).

In order to reduce costs, increase responsiveness, and improve resource allocation, optimizing several supply chain management procedures is a key component of supply chain efficiency such as managing inventories, manufacturing procedures, and transportation (Moons et al., 2019). By lowering operating costs, maximizing resource utilization, and speeding up order fulfillment, this efficiency directly affects SMEs' bottom line (Le et al., 2022). Therefore, higher profit margins, better cash flow, and a higher return on investment are all impacted by enhanced supply chain efficiency (Siagian et al., 2021).

Moreover, SMEs' earnings and financial well-being are further positively impacted by an efficient supply chain, which additionally results in higher retention and satisfaction with clients (Gorane et

al., 2017). This complex relationship emphasizes how important strategic supply chain management is for fostering operational excellence as well as influencing SMEs' financial strength in a cutthroat business environment (Naughton et al., 2020).

3.7.5 Performance Determinants in Supply Chain Management: Enhancing Efficiency and Effectiveness

The performance of supply chain management involves both effective and efficient operation. Any attempt to increase supply chain efficiency is likely to be ineffective if effectiveness is not given the same priority. The effectiveness and efficiency of supply chain management are assessed, and these factors are typically accompanied by goals like expenses, quickness, reliability, quality, and flexibility. Supply chain efficiency, a gauge of how well an organization's supply chain operations use its resources, is an internal performance standard.

It determines how successfully a company's supply chain employs the resources at its disposal to achieve cost-saving objectives. An external measure of an organization's ability to satisfy the needs and expectations of the different supply chain stakeholders is its supply chain effectiveness. Greater effectiveness in supply chain activities leads to improvements in service quality, while greater efficiency yields significant cost savings.

While efficiency measures how financially the supply chain's resources are used to provide a predetermined level of customer satisfaction, effectiveness measures how well a customer's expectations are met in the supply chain (Madhani, 2021). Enhanced profitability, lower expenses, higher revenue, and eventually higher enterprise value are all attributed to improved supply chain efficiency and effectiveness.

3.7.6 Challenges and Hurdles in Attaining Supply Chain Efficiency

To be efficient, supply chains must overcome a number of difficulties. There are several difficulties and barriers in maintaining an efficient supply chain. One difficulty is the outside influence competitors place on businesses, which can cause supply chain disruptions and impair contract fulfillment (Ye, 2022). Uncertainty surrounding contract performance is another issue that raises costs and decreases transaction efficiency (Lara et al. 2023).

Customer satisfaction and company reputation can also be harmed by inefficient logistics scheduling and distribution. Furthermore, supply chains frequently don't do a thorough analysis of the potentials and behaviors of their customers, which makes it challenging to draw actionable conclusions about demand variation. Challenges related to scalability and decision-making integration across various time horizons and internal business units are shared by the process and e-commerce industries (Melnyk et al., 2022).

Supply chain management is impacted by globalization, outsourcing, and supply and demand uncertainty, as noted by (Hofmann et al., 2006) and (Piya et al.,2017). These elements add to the complexity of supply chains, which is made worse by the requirement for quicker and more efficient decision-making (Piya et al.,2017). The increasing importance of sustainability and the need for supply chains to be flexible, agile, and aligned with the goals of all stakeholders are emphasized by (Barbosa-Póvoa., 2009) and (Lee., 2004).

The difficulties in managing supply chain disruptions and the requirement for integrated supply chain management are emphasized by (Bala., 2014) and (Stevens.,1990), respectively. In order to address these issues, (Papageorgiou., 2009) talks about the importance of uncertainty and the possible advantages of supply chain reengineering.

3.7.7 Attributes, Key Components, and Principal Specifications of an Efficient Supply Chain

Supply chain management efficiency is a complex idea that includes aspects of economic, functional, and service quality. It is essential for low-cost, high-quality product production and delivery with short lead times (Lichociket al., 2013)

In light of market concentration and strategic alliances, supply chains' resilience is especially crucial. Network-based operations can help manufacturing companies become more competitive (Nagy et al., 2021).

Achieving efficiency requires integrating the supply chain and utilizing information technologies. It is emphasized how important is to manage the supply chain from a tactical, operational, and strategic standpoint (Charlampowicz, 2018). A proposed model aims to enhance the efficiency and effectiveness of the supply chain by emphasizing profit, lead time performance, prompt delivery, and waste elimination. Finally, a framework that takes into account both economic and environmental performance is presented for creating eco-efficient supply chain networks (Colicchia et al., 2016).

Integration between manufacturers, suppliers, warehouses, retail locations, and customers is necessary for an efficient supply chain. It entails streamlining scheduling, distribution, manufacturing, and resource planning. Numerous methods and tactics have been put forth in the literature. A few of these involve utilizing data envelopment analysis (DEA) models to gauge the retail supply chain's efficiency (Andrejic., 2023), designing supply chain networks using various approaches to demand management (Celikbilek et al.,2016) applying meta-heuristic Algorithms to supply chain management optimization (Srinivasan., 2019) creating lean, agile, and leagile supply chain strategies to efficiently match supply and demand (Madhani., 2017) and scheduling in a supply chain network under demand uncertainty using MILP-based techniques (Aguirre., 2018).

These methods and techniques seek to reduce expenses, raise client contentment, and create a more reliable supply chain. Numerous studies have looked into the key components and methods of an effective supply chain. Designing and managing the supply chain effectively is essential, as mentioned by (Talluri et al., 2002) and (Stevens.,1990), the latter of which emphasizes the necessity of integration at the tactical, operational, and strategic levels. Decision modeling is the subject of (Li et al., 1999) and (Amaro et al., 2004), respectively, with Li's model taking profit, delivery promptness, lead time and waste elimination into account.

The impact of demand variability and market conditions on supply chain efficiency is discussed by (Charlampowicz., 2018) and (Escobar., 2017), respectively. The former suggests a resilient supply chain strategy and the latter takes financial criteria and scenarios into account. The role of optimization in supply chain design is examined by (Colicchia et al., 2016) and (Bok et al., 2000).

While Bok's model addresses operational decisions in continuous flexible process networks, Colicchia's framework identifies eco-efficient configuration alternatives.

A successful supply chain has several essential components and goals. Among them is logistics performance, which maximizes the use of resources, technology, and knowledge to create growth rewards and accelerate economic growth (Alshuridehet al., 2022). Information technology, top management backing, and internal integration are further crucial elements that enhance supply chain performance.

Furthermore, information exchange with the organization's internal and external environments is essential for controlling the flow of materials and information throughout the supply chain (Daneshvar et al.,2020; Rut et al., 2018). An efficient supply chain reduces expenses, simplifies procedures, and frees up time for other uses. Additionally, it enables response to customer needs more quickly and save money across the whole supply chain (Dastani et al.,2022; Junejo et al., 2022).

Overall, increasing productivity, cutting expenses, obtaining a competitive edge, and increasing customer retention are the primary objectives of a successful supply chain. Information technology, top management support, and internal integration define an effective supply chain (Daneshvar et al.,2020). It is intended to balance the chain's overall benefits while meeting customer service goals (Li et al., 1999). For businesses to achieve this, they must assess the supply chain, assess the competitive landscape, and create internal, external, and functional integration (Stevens.,1990). Efficiency in the global supply chain is influenced by a number of factors, including distribution, processing, and procurement. Supply chains that contain uncertainty present a significant challenge that must be overcome (Papageorgiou., 2009; Prasad et al., 2003).

3.7.8 Advantages and Benefits of Efficient Supply Chain Operations

An efficient supply chain offers several benefits and advantages.

First off, by making the most use of available resources, technology, and knowledge, it helps to reduce logistical costs and increases revenue (Alshuridehet al., 2022).

Second, it makes it possible to streamline steps and processes, which reduces costs and frees up time for other purposes (Alomari et al., 2020).

Thirdly, obtaining a competitive edge in the market is facilitated by an efficient supply chain. It helps businesses to improve overall performance, control the flow of materials and information, and optimize operations (Daneshvar et al.,2020; Rut et al., 2018).

Moreover, the supply chain's performance is positively impacted by an efficient supply chain strategy, which enhances business performance (Mor et al., 2019). Achieving organizational goals and competitive advantages also depends on it. All things considered, productivity, cost savings, and obtaining a competitive advantage in the market depend on an efficient supply chain. Numerous advantages of an efficient supply chain include risk mitigation, profit maximization, network optimization, and cost reduction (Olatunji et al., 2019).

Lastly, through the implementation of Sustainable Supply Chain Management (SSCM) and the integration of sustainability into the supply system, an efficient supply chain aims to improve

supply chain operations while pursuing business objectives from an economic, social, and environmental standpoint through the deployment of cutting-edge IT systems and efficient information sharing with the organization's internal and external environments and it aims to reduce risk uncertainty and achieve cost and time efficiency in the production process (Rut et al., 2018; Sembiring et al. 2019).

3.8 Supply Chain Visibility and Traceability

Accurately identifying and gathering data from every supply chain link is known as visibility, or traceability. A crucial element of supply chain management is tracking a product's journey through the supply chain. Disclosure is the sharing of information both internally and externally at the degree of specificity that is necessary or anticipated (Choi et al. 2020). The ultimate goal of collaboration along the entire supply chain is Supply Chain Visibility in order to combat data fragmentation (Samaranayake, 2005). "The identity, location, and status of entities transiting the supply chain, captured in timely messages about events, along with the planned and actual dates/times for these events" is what supply chain visibility (SCV) is all about (Francis, 2008).

Formally speaking, traceability is defined as knowing an entity's location and history through any recorded identification, whether the entity is external to the organization or internal. The procedure differs depending on the product and the industry. Processing and manufacturing start at the source of each component and continue through transportation, processing, packing, and distribution before reaching the final consumer. In the fields of agriculture, farming, and fisheries, identification starts when grain is planted or when a cow is born, and it continues through all the stages leading up to market transportation, including growth, pesticide use, and keeping animal care and nutritional records. Similar to this, the transportation, distribution, manufacturing, and manufacturing procedures in addition to additional facets of the retail and food services supply chain all adhere to a number of consistent principles for traceability.

A product's integrity can be guaranteed throughout the supply chain with traceability, but managing this process can be difficult. Non-line-of-sight technologies like radio frequency identification (RFID) and code-carrying technologies are examples of technological solutions for tracking and documenting the movement of goods. Pallets, cases, packages, and individual items are frequently equipped with RFID tags, which are becoming an essential component of the supply chain (Jabbar et al. 2021).

According to (Musa et al., 2014), traceability improves process controls and product security but does not address more fundamental risks. According to (Janssen-Vullers et al. 2003), traceability is passive and tracks a product's movement through supply chain nodes, but it does not provide visibility into the activities taking place at those points (Kwon et al., 2018). Visibility provides what traceability cannot because supply chain risk is present in the materials used (Mohammaddust et al., 2017), processes used (Ciccullo et al., 2018), and people involved (Gold et al., 2015). According to (Abeyratne et al., 2016), Managers of supply chains cannot observe what is done, by whom, and based on what results at each node. Managers cannot take action based on data that is not provided by traceability (Parry et al., 2016). Fraudulent transactions, theft, a lack of social responsibility, and subpar environmental performance are all possible problems for modern supply chains. Improving the supply chain's visibility is a crucial tool for addressing these issues and worries. Enhancing supply chain transparency and contributing to the mapping of supply

chain networks, along with disseminating accurate, dependable, and secure information about supply chains and sustainable practices, can all help to raise visibility.

Transparency then offers chances to improve the global supply chains' social and environmental sustainability. Supply chain partners must encourage transparency; those who do not uphold these standards will lose market share, relationships, and reputation. Encouraging supply chain sustainability and transparency, however, is a difficult task that requires careful consideration, particularly in the supply chains for agriculture in developing countries. The advent of the fourth industrial revolution has led to the emergence of a number of new, disruptive digital technologies that aim to improve supply chain transparency, authenticity, and information efficiency (Saberi et al., 2019; Rajesh, 2020; Gualandris et al., 2021; Chunguang et al., 2022).

3.8.1 The Relationship Between Supply Chain Visibility and Efficiency

Having access to the precise, timely, and useful information that defines Supply Chain Visibility has several advantages. Supply chain experts view visibility as a critical facilitator of cross-organizational cooperation, facilitating integration across tiers up to and including the customer, enhancing trust, and boosting efficiency. Thus, visibility lowers decision risk and promotes actions in the supply chain. Because it gives businesses "capabilities to reorganize their supply chains and generate strategic value," this enhances supply chain performance overall.

Visibility is essential for many successful SCM processes, such as cost, inventory control, and physical logistics. Efficient use and, more importantly, information sharing with suppliers can improve supply chain partners' responsiveness, improve essential metric layout and measurement, boost productivity, improve customer service, and improve overall business performance. Managers running efficient supply chains must be able to process the enormous volumes of data generated in order to make decisions. Due to information asymmetry created by centralization, which usually favors larger organizations or IT system implementers, traditional supply chain centralization has not provided that opportunity to all parties, preventing the optimization of supply chain efficiency (Rogerson et al., 2020; Michalski et al., 2018; Treiblmaier, 2018).

3.9 Integration of Technology in Supply Chain

In the forthcoming chapter of this research, we aim to elucidate blockchain technology and its associated concepts, focusing on its intricate relationship with the supply chain. This preliminary section provides a succinct overview of the interplay between supply chain dynamics, various technologies, and expounds on the strategies for successful technology integration within supply chain frameworks.

Though the increasing use of ICTs in Supply Chain activities has also increased operational complexity for businesses across all sectors, emerging information and communication technologies (ICTs) have been hailed as answers to complex problems in Sustainable Supply Chain Management. In particular, emerging ICTs are challenging customs in the workplace, which is compelling businesses to adjust their supply chain practices in response to digitization.

Given that ICTs are becoming inextricably linked to Sustainable Supply Chain Management, an innovative stage of functional integration (e.g., enterprise resource planning system) involving blockchain labels that incorporate accountability and transparency from end-to-end SC transactions between members in a multi-tier supply chain is rapidly emerging. (Sahoo et al., 2022; Tang et al., 2019; Gurtu et al., 2019; Wamba et al., 2022: Chod et al., 2020).

A range of sensing, communication, storage, and processing technologies, including data science, cloud computing, edge/fog computing, 5G, and the Internet of Things (IoT), have improved digital capabilities within the supply chain's organizational layers. The supply chain system is being driven toward greater process standardization and integration thanks largely to this digital initiative. Today's disruptive trend regarding digital supply chains is helping companies like Uber, Careem, Alibaba, Netflix, and Airbnb.

Some technologies enabling the execution and governance of goods dealing with at various stages of a supply chain are delivery drones, robotic goods handling, pick-and-drop autonomous vehicles, certificate systems, eHealthcare systems, and vision picking in warehouse processes. End-to-end track and trace relies on the seamless technological interconnection of supply chain silos to form a coherent system from disparate parts (Jabbar et al., 2021).

3.9.1 Integration of Emerging Technologies in Supply Chain

Organizations in the supply chain need to make sure they can quickly adjust when challenges arise. because their supply chain is unreliable, the majority of organizations struggle with issues related to data integrity, data sharing, and data visibility with suppliers and buyers. As a result, businesses are working to digitize supply chains by implementing cutting-edge technologies like blockchain to enhance data quality, integrity, and visibility. Businesses will be able to react swiftly to obstacles thanks to this.

For supply chain companies and businesses overall, increased speed, flexibility, sustainability, decreased risk, and enhanced customer confidence were just a few of the advantages that resulted from improved data quality, integrity, and visibility. Blockchain technology is thought to be the most innovative and promising technology that could have a big impact on businesses worldwide because of its transparency, efficiency in processes, and security features. (PwC, 2017).

By giving them operational efficiency, security, decentralization, immutability, and transparency, it promises to streamline shortcomings of business processes both within and between organizations (Falazi et al., 2019). The application of blockchain technology has potential benefits for enhancing supply chains' responsiveness and resilience to market fluctuations. Research on using blockchain technology in supply chains has become more popular (Rubio et al., 2018; Ivanov et al., 2019; and Panetto et al., 2019; Kshetri, 2018) and backs the novel idea that the deployment of different ICTs (information and communications technologies) such as blockchain, Internet of Things (IoT), big data, etc. behind supply chains is what's competing, not the supply chains themselves.

In conjunction with additional technologies, such as the Internet of Things, blockchain has the potential to produce a permanent, shareable, and actionable record of every step a product takes through its supply chain. This could lead to increased productivity, better visibility, and improved product traceability, legitimacy, and authenticity. Increased traceability makes the supply chain more transparent. The Internet of Things and blockchain technology can be used together to build

value chain systems that guarantee supply chains' transparency and traceability (Borah et al., 2020).

3.9.2 Supply chain and industry 4.0

Technology is developing quickly, and supply chains may benefit from this progress. Organizations can use it to develop new goods, services, and procedures that will boost output and give them a competitive edge. Globalization and other external factors make it necessary for supply chains to keep up with emerging technologies. A large portion of the advancements in digital technology are contained within the fourth industrial revolution, or Industry 4.0.

Industry 4.0 refers to the movement in the technology and processes of the industry toward automation, collaboration, integration, and data exchange both horizontally and vertically. Industry 4.0 aims to empower companies to automate workflows, decrease dependency on human labor, adapt to evolving customer demands, shift to self-sufficient operations, and more.

The Internet of Things (IoT), robots, sophisticated human-machine interfaces, 3D printing and additive manufacturing (AM), augmented and virtual reality (AR), artificial intelligence (AI), big data, and blockchain are some of the Industry 4.0 technological innovations that are quickly changing supply chains throughout the world. The products provide businesses with previously unheard-of capabilities that could have a big impact, like real-time data analysis, visibility, comprehensive decision-making, higher productivity, and improved competitive advantage. Global efforts are being made in large measure to integrate technologies to build creative, networked, and sustainable supply chains.

Blockchain is important in the framework of the fourth industrial revolution. Anonymity and identity, a consensus mechanism, decentralization, performance in general and expectation, system and data reliability, and transparency define blockchain as a disruptive technology. procedures that greatly increase productivity and are based on intelligence and learning. Supply chains can benefit from Industry 4.0 technologies that promote transparency, and blockchain technologies have been studied more and more, with an emphasis on system architectures and structures that facilitate transparency (Sunmola et al., 2023; Manda et al., 2017; Pousttchi et al., 2019; Matt et al., 2015; Ulas, 2019).

Summary

The application of blockchain technology to supply chain management is examined in this chapter, emphasizing its potential to transform business operations and supplier interactions. It emphasizes the importance of sustainability in supply chain management, which involves coordination and management of activities related to product and service production and delivery. The United Nations defines sustainability as having three main pillars: environmental, social, and economic sustainability.

The difficulties and possibilities of sustainable supply chain management are also covered in the document, focusing on the pharmaceutical and food industries. It emphasizes the need for transparency and efficiency, as well as the application of information technology to streamline processes. The document also highlights the importance of logistics performance, information

technology, top management backing, and internal integration in enhancing supply chain performance. It also highlights the significance of traceability in ensuring product integrity.

The document introduces the concept of Industry 4.0, which focuses on automation, collaboration, integration, and data exchange. It draws attention to how these technological advancements such as blockchain, robots, artificial intelligence, and the Internet of Things can give businesses access to real-time data analysis, visibility, thorough decision-making, increased productivity, and a stronger competitive edge.. It also addresses the unexpected worldwide chip shortages in 2021 and emphasizes the need for mechanisms to achieve best supply chain earnings and coordination in decentralized firm decisions.

4 Blockchain

4.1 Blockchain Definition

Blockchain is one of six computing "mega-trends" that the World Economic Forum (WEF, 2015) believes will have a significant impact on global affairs over the decade that follows. Blockchain technology is a revolutionary development in technology that has a big impact on the contemporary business landscape. Among digital technologies, blockchain is one of the newest and fastest-growing ones that can support sustainable manufacturing. A distributed and decentralized data structure is what blockchain technology offers. The primary features of blockchain technology, acknowledged as the primary advantages, are auditability, decentralization, persistency, and anonymity.

Any transaction can be carried out decentralized thanks to blockchain technology. As a result, expenses can be significantly decreased and productivity can be raised (Zheng et al., 2018). Blockchain technology creates a unique data structure and an encrypted, fault-resistant distributed ledger as a novel digital method of preserving data integrity (Elmessiry et al., 2018). Following Satoshi Nakamoto's invention of Bitcoin in 2008, the idea of blockchain technology surfaced (Nakamoto, 2008). Bitcoin is an electronic currency that enables online exchanges between parties without the use of intermediaries like banks.

The network that facilitates the transactions is commonly referred to as a blockchain network. In essence, a blockchain network offers decentralized, secure, and immutable data storage (Xu et al., 2016). This indicates that once the database is in the blockchain system, it can only be added to or updated. It cannot be edited. Only when all relevant networks reach a consensus can the data in the system be updated. With the aid of a cryptographic key, blockchain technology solves the double-spend issue (Pilkington, 2016).

A private key is given to each responsible individual at each blockchain network node, and the public key is shared with everyone else. The transaction begins when the original owner of cryptocurrency (digital tokens or digital representations of other assets) shares his or her public key with the subsequent owner.

This transaction is combined with other pending transactions to form a "Block." It is now possible for multiple nodes to create multiple blocks concurrently. A mathematical puzzle known as "proof of work" was introduced to determine which block in the blockchain ought to become the next one (Crosby et al., 2016). Once the "block"'s location has been established, it is forwarded onward through the blockchain system's network of involved computers, which uses mathematical computations to assess the transactions and establish the database's validity.

Once consensus has been reached, evaluation is conducted according to established guidelines in what is known as the verification stage. The blocks are time-stamped with a cryptographic hash that contains a reference to the hash of the previous block after verification. This creates an unchangeable "chain" of records. After completing these steps, the transaction is finished. The fundamental flow diagram of a basic blockchain network is shown in Figure 4. Blockchain was initially used in the financial industry to substitute digital authentication for human transaction authentication for cryptocurrencies.

Figure 4. Flow diagram of the blockchain. (Awwad et al., 2018)

Due to its potential to improve data security, immutability, traceability, transparency, and trust, academics and professionals from a variety of industries have expressed interest in blockchain technology. The primary goal of the blockchain, which developed alongside Bitcoin, was to offer a safe network for the transfer of virtual money (Nakamoto, 2008). However, due to its many advantages including data immutability, transparency, traceability, and many more, blockchain technology is now beginning to transform business and industry (Zheng et al., 2021; Francisco et al., 2018). It is still thought that blockchain technology is in its early stages of development, and not a lot of study has been done in this area. The amount invested in blockchain solutions is predicted to increase rapidly, reaching USD 176 billion by 2025 (KPMG, 2018).

The manufacturing and supply chain sectors can enhance their practices for economic, social, and environmental sustainability by making use of blockchain technology's exciting potential. Sustainability's importance in the manufacturing sector has led to a growing scholarly curiosity about how blockchain technology can improve manufacturers' sustainable performance (Ko et al., 2018; Kshetri, 2021; Leng et al. 2020). It will take some time before potential users of this technology fully depend on and make use of it. By using the adoption of Transmission control protocol/Internet Protocol, which served as the basis for the Internet, as an example, (Iansiti et al., 2017) did a very good job of explaining the phases of technology adoption.

TCP/IP took over 30 years to go through all the adoption stages and change the economy after it was first introduced in 1972. Blockchains have been used recently in the manufacturing (Abeyratne et al., 2016), logistics (Pournader et al. 2020), supply chain management (Saberi et al. 2019), financial services (Zeng et al. 2018), and healthcare (Mettler, 2016), However, scalability and security challenges remain to be addressed. (Thakur et al., 2023) By promoting transparency, blockchain technology can also enhance or fulfill the potential of sustainable supply chains (Bai et al., 2020; Kouhizadeh et al., 2021). Leveraging blockchain technology in the supply chain is the exclusive topic of this essay.

4.2 Enhancing Operational Practicality: A Focus on Blockchain Technology Implementation

Blockchain is an emerging technology that can be simplified to a shared list that is difficult to change. The term "blockchain" refers to the Bitcoin variant of distributed ledger technology (DLT), but it has also come to refer to DLT in general. There are several DLTs available, such as Ethereum, a distributed applications platform that is available globally and can be used to implement smart contracts (Zheng et al., 2018). Those that are executed automatically when certain conditions are met on a blockchain-enabled system (Abeyratne et al., 2016).

A comprehensive discussion of DLT and its various types is beyond the scope of this paper; reviews are available elsewhere (Rossi et al., 2019). Blockchain has been widely used in one of three models: public, private, and consortium. Blockchain is currently gaining popularity in a wide

range of industries, including finance, health care, other sectors, utilities, and the government sector. The reason for this increasing interest: Blockchain enabled applications that only worked through a trusted intermediary. They can now function decentralized and maintain the same functionality and reliability without requiring a verification system. This was not possible before the blockchain was developed.

With the implementation of blockchain, trustless networks emerged. This is possible because blockchain networks allow you to transfer funds without having to trust other users. Transactions between users become faster when no intermediaries are involved. Additionally, the blockchain's use of cryptography guarantees the security of the data. Blockchain is a massive accounting ledger that records every transaction made by users. This prompts Internet of Things (IoT) researchers and developers to seek out ways to connect IoT and blockchain (Casado-Vara et al., 2018).

4.3 Cryptography and Blockchain

(Haber et al., 1992) demonstrated the concept of a cryptographically secured chain of blocks, After that, (Nakamoto, 2008) attempted to use BC, and he / she used this technology to create Bitcoin, the popular cryptocurrency. Bitcoin is referred to as Block chain in the original paper by (Nakamoto, 2008). This technology operates on a distributed ledger of information (Nakamoto, 2008). As the name implies, it is made up of several blocks, each with its own address information. Each block has a distinct identity and contains unique information.

The information contained in Bitcoin cannot be changed, erased, or updated. If you want to change any of the information, you must create a new block. Because of this distinct and unique quality, traceability and auditing at any stage of the supply chain become more efficient and effective. (Rayes et al., 2017) proposed that it make the system highly efficient with a fast transmission rate. Bitcoin also reduces costs and improves quality when compared to the traditional supply chain. Recently, the manufacturing organization began implementing BC to improve supply chain performance (Yadav et al., 2020).

4.4 Variants of Blockchain Technology: A Brief Overview

Blockchain is divided into three types: public, private, and hybrid.

A public blockchain is a permissionless network that is accessible to anyone. Anyone can join the network and participate in this type of blockchain by learning, creating content, or interacting outside of it. A public blockchain is decentralized, with no central authority governing the entire network. Additionally, once verified on the blockchain, data on a public blockchain cannot be altered or modified, making it secure.

A private blockchain is permissioned because it is managed by a network operator and can only be joined by approved users. Because a small number of entities control the network, transactions must be processed through third-party intermediaries. This kind of Blockchain keeps the transaction private by only allowing the parties involved to know about it. No one else will be able to access it.

A hybrid blockchain combines elements of private and public blockchains. It aims to balance the benefits of both blockchain techniques while minimizing their drawbacks. It has applications for businesses that want to take advantage of the integrated benefits of private and public blockchains. A Blockchain network can support both a private permission-based and a public permission-less system. A consortium blockchain, on the other hand, aims to do away with the single-entity independence of private blockchains.

A consortium blockchain, unlike a private blockchain, has multiple entities on the network. The control's decentralized nature is maintained because no single authority has control over it. Figure 1a. depicts the key features of these blockchain techniques, while Figure 1b. depicts the differences between the various types of blockchain technologies. The major drawbacks of using private blockchain are listed below:

Building trust: Comparatively speaking, a private network has fewer users.

Reduced security: A private blockchain network has fewer nodes or participants, making it more vulnerable to a security breach.

Private block chains are limited by their reliance on a centralized Identity and Access Management (IAM) solution. This system provides comprehensive managerial and tracking capabilities (Uddin et al., 2023).

Here are the key features and claimed benefits of blockchains:

• Disintermediation: Blockchains are peer-to-peer networks, which reduce reliance on third parties.

• Transparency through pseudonymity: Blockchains contain information that is viewable by all participants and cannot be altered by a single entity, thereby increasing trust and decreasing fraud. Users can choose to remain anonymous or show proof of their identity to others.

• Automation: Blockchains can be configured to automatically start events (like payments or other actions) between nodes when specific criteria are reached. The idea of smart contractscomputerized transaction protocols that carry out the terms of contracts is made possible by this attribute.

• Security: In order to guarantee that the recording in the database is permanent, arranged chronologically, and accessible to everyone else on the network, a number of computational algorithms and techniques are used. Blockchains are hard to hack because they are distributed and encrypted.

4.5 Smart Contracts

Computer code that can be programmed and run in a blockchain is known as a smart contract. Cryptography writer Nick Szabo (Szabo, 1994) led to the development of smart contract concept in early 1990s. (Njualem, 2022). Blockchain technology's revolutionary feature, smart contracts, automate agreements and transactions while maintaining security, efficiency, and transparency, transforming a number of industries.

By executing predetermined conditions autonomously (Delmolino et al. 2016), these contracts which are embedded within blockchain platforms eliminate the need for middlemen and increase trust between parties involved in transactions. They are especially important for supply chain management (SCM) because they reduce costs, optimize workflows, and promote transparency across the supply chain network (Sahoo et al. 2022; Tsolakis et al., 2021; Esmat et al., 2021). First of all, smart contracts function as blockchain-recorded programs that become active when certain conditions are satisfied. They facilitate the automatic implementation of agreements, safeguarding the finances and reputations of all parties involved and promoting confidence.

Through the utilization of blockchain's peer-to-peer architecture and scalability, smart contracts facilitate quick financial settlements without depending on reliable middlemen. Smart contracts are employed by companies in supply chain management (SCM) to facilitate the transmission of critical data, including contract details, work performance, and compensation terms. This lowers transaction costs, eliminates the need for intermediary businesses, and boosts profit margins. Furthermore, the immutability of blockchain technology guarantees the safety and reliability of data transferred through smart contracts, reducing the likelihood of fraud or theft throughout the supply chain (Hasan et al., 2019; Pournader et al., 2020; Dolgui et al., 2020).

Supply chain management is more transparent when smart contracts are used to allow all parties to track and monitor products all over the supply chain. Because smart contracts are decentralized and execute transactions based on network participant consensus, they automatically verify contractual terms, promoting transparency, accountability, and trust. Furthermore, data sharing between supply chain participants is regulated by smart contracts, allowing for continuous and real-time product status monitoring.

One characteristic that sets smart contracts apart from traditional contracts is that they are deterministic and automatic, which removes the possibility of human error or decision-making delays. Smart contract coding allows supply chain management (SCM) stakeholders to reduce risks like fraud and guarantee the integrity of components, raw materials, and final goods (Saberi et al., 2019; Delmolino et al., 2016; Maurer, 2017).

Even though smart contracts were first conceived of decades ago, their widespread adoption was hampered by both financial and communication infrastructure constraints, but thanks to developments in blockchain technology, smart contracts are now a useful and essential tool for supply chain management in the modern era. They provide unmatched security, efficiency, and transparency. To sum up, smart contracts are a revolutionary development in blockchain technology that will transform supply chain management (SCM) by automating contracts, improving transparency, and reducing the risks involved with conventional contract arrangements. By reducing costs, increasing stakeholder trust, and streamlining supply chain operations, their implementation is expected to usher in a new era of accountability and efficiency in international supply chains (Watanabe et al. 2015; Chang et al., 2020; Omohundro, 2014).

4.6 Distributed Ledgers

Blockchain comprises nodes, which stand in for active network users. These nodes are used by distributed ledgers to record, distribute, and synchronize transactions throughout the network. To obtain a copy (cryptographic hash) of every previous transaction, this replicates into further

nodes that eventually join the chain. It is important to remember that not every distributed ledger is blockchain because the distributed ledger feature is exclusive to blockchain technology. As previously mentioned, this feature lays the foundation for a decentralized framework.

By enabling direct user transactions, decentralization removes the centralized tackle and addresses information inequality (Perboli et al. 2018) Efficiency and transparency are the advantages of this kind of infrastructure. All network users have control over data and transactions to promote transparency. Another way to achieve efficiency is with a synchronized network, which reduces transaction time. Reproducible distributed network infrastructure can be found in a supply chain, no matter how big the chain appears to be. The search for sustainability metrics in a convoluted supply chain heavily relies on information accessibility and openness within the network (Njualem, 2022).

4.7 Immutability

An essential feature of blockchain technology is immutability. In a supply chain, where downstream collaborators often find themselves at the mercy of their upstream peers in matters of material composition, provenance, and much more, a system free of data integrity problems is ideal. This is a crucial part of a supply chain that is sustainable. It is critical to trust the data that comes in, and ensuring its originality is a good way to earn that trust. Any modification made to data in the blockchain is visible to all participants and is followed by another transparent block attachment to the chain.

A transaction is never altered once it is entered into the system and users receive a verified signature (Park et al., 2021). A blockchain may become susceptible to manipulation by a single network node. If that organization controls more than half of the blockchain network's nodes, this might occur. However, the immutability feature can reduce the amount of human error in records (Duan et al., 2020) and stops the risks of incorrect or improperly manipulated data changes that are present in manual and more centralized systems. However, immutability can only be achieved if network nodes distribute evenly.

4.8 Consensus

In a network, security is most important. Data security is ensured by BCT's consensus feature. A transaction in the blockchain can be enabled by a consensus of all users within the network. The decision made by participants to govern the addition and updating of data on a blockchain is known as a consensus. The consensus algorithm's underlying principle is that the state of the ledger should be agreed upon by the majority (or, in certain situations, all) of network validators.

It is defined by a set of guidelines and protocols to preserve coherency amongst several participating nodes (Irannezhad, 2020). Mechanisms are used in blockchain technology to guarantee the reliability of the agents, protocols, and rules that produce changes in the blockchain. Common examples are proof of importance, proof of authority, and proof of work. These are essential elements that promote data security and may assist in resolving trust concerns among supply chain participants after a sustainability investigation (Njualem, 2022).

4.9 Blockchain Decentralization

One key feature of blockchain technology is decentralization, which increases the validity of information by acting as a check on any information adulteration. Distributed public or private ledgers provide participants with verified records of every transaction, and it is not possible to remove records that have been jointly maintained (Crosby et al., 2016). A centralized database has a higher risk of corruption, hacking, and crash (Tian, 2016). One of decentralization's primary outcomes is trust, as information can be viewed and compared with ease and there is no need to evaluate the credibility of the intermediary or other network participants (Nofer et al. 2017).

This strategy depends on underlying technology to maintain the integrity of the system even in the face of fraud or inactivity, rather than expecting participants to behave a certain way. Participants can examine the ledgers and analyze transactions. By protecting records behind cryptography, this feature ensures anonymity while simultaneously providing transparency (Tian, 2016; Crosby et al. 2016). Blockchain technology can be used widely to create a set of norms that are accepted by all parties and that users and system operators cannot break. For applications involving numerous individuals that need little trust in each other, such as fragmented supply chains, they rely on a special platform for system architecture (Saberi et al., 2019).

4.10 Blockchain Core Improvement

Peer-to-peer systems load IoT devices with heavy processing and storage loads. Contrary to heterogeneous IoT devices, many nodes are built and equipped with the best resources for processing and verifying transactions in the mining and cryptocurrency space. A few key features of the Blockchain can be changed to improve the way IoT devices integrate with DLT technology.

The Blockchain can be modified and adjusted to meet IoT requirements in three areas: block size, creation time, and consensus algorithm. The improvements made to the transaction format have a greater influence on data transparency than the others. As it stands, the transaction is missing a lot of crucial information. Therefore, there will be more difficulties with data transparency when the transaction format is developed to include references, block info, and real identities, among other things (Hellani et al., 2021).

4.11 Blockchain Technology Applications: A Synopsis

According to (Mengelkamp et al., 2018), blockchain, the technology that powers Bitcoin, a cryptocurrency that is well-known for data security, has recently been tested in various circumstances. One such context is community-owned green energy networks. supporting smart contracts and land registries in emerging economies. Supply chains are finding more and more applications for blockchain technology. The qualities and features of blockchain technology, such as data security, traceability, transparency, and real-time information sharing, can be advantageous to a variety of industries (Ko et al., 2018; Fu et al. 2018; Esmaeilian et al., 2020). For instance, in the agri-food industry, blockchain technology could be integrated with other technologies, such as RFID, to monitor food supplies in real-time.

This could improve food safety and quality, streamline food operations, and lessen unethical behavior and social harms (Saurbah et al., 2021). The financial industry can make use of blockchain technology to decentralize financial institutions, trace transactions, and eliminate

banks (Abeyratne et al., 2016). Blockchain technology can improve patient data accuracy and confidentiality in the healthcare industry. Furthermore, blockchain can reduce healthcare costs while improving the quality of care provided to patients. In addition to reducing healthcare fraud, blockchain technology can improve patient transparency.

Blockchain is applied in the automotive industry to advance driving technologies and to secure and prevent automated cars from being compromised. Blockchain-based technologies improve autonomous vehicles' performance and help cut down on emissions and fuel consumption (Upadhyay et al., 2021). Because of its many advantages including data security, decentralization, real-time information sharing, and trust blockchain technology is one of the most important tools in the development of smart cities (Sun et al., 2020).

Blockchain can also be used as a middleware to combine Industry 4.0 smart manufacturing with technology breakthroughs. Information sharing, increased security, cost savings, and increased organizational efficiency can all be facilitated by this integration (Mohamed et al., 2019). Blockchain technology has applications in the medical field to enhance oversight of the drug supply chain and make it easier to identify counterfeit medications (Badhotiya et al., 2021).

4.12 Blockchain design

Blockchain designs vary depending on the technology application and can create networks and ledgers that are either public (permissionless) or private (permissioned). Regarding the participants in the network and the regulations governing the upkeep of the blockchain, their designs differ. A closed or private blockchain eliminates anonymity by allowing parties to know one another, much like in a supply chain network where well-known companies collaborate to manufacture and distribute goods.

In this scenario, new positions would emerge, such as certifiers, who uphold this private network and grant certifications to supply chain network users. Alternatively, cryptographic techniques are used in public or open blockchains to allow users to join the network and log transactions while preserving trust with a large number of anonymous users (Ølnes et al., 2017; Pilkington, 2016).

4.13 Factors Influencing Organizational Adoption of Blockchain Technology

When it comes to external factors, the supply chain and the market are the main ones that influence an organization's willingness to explore blockchain technology. Other motivators center on some of the features that blockchain technology can offer, particularly information security requirements and information traceability. Savings are a key factor in business. Organizational, supply chain, technological, and external (to the supply chain) limitations were the four main categories of barriers that mentiones previously (Saberi et al., 2019).

Organizational knowledge and support systems are the main internal organizational barriers, according to respondents. The two main supply chain obstacles to considering blockchain were supplier cooperation and coordination as well as customer awareness (knowledge). In general, the available infrastructure and the immaturity of the technology were the main concerns, both in

terms of external barriers and technology. The respondents' top concerns were also uncertainties in the market and industry. For the benefit of the readers, a slightly more nuanced assessment of industry-specific pressures and motivators is finished here.

Although there are many more detailed assessments available, this preliminary analysis offers some insights that organizations may find helpful in benchmarking their circumstances. "Reducing Operations Cost" was generally the most significant motivator for all of the companies, while "Low Cost of Technology Implementation" was the least significant. It is evident that every business prioritizes cutting expenses associated with daily operations. Furthermore, the benefits of implementation are cumulative, meaning that the initial outlay is offset by time. Companies can benefit greatly from blockchain technology, and surprisingly, implementation costs are not always a barrier to adoption. Table 1. lists the main Motivators and Barriers to considering blockchain technology.

Table 1. Top Motivators and Barriers for Blockchain Technology Consideration (Saberi et al., 2019b)

Pressures	The need for collaborating with supply chain partners. Customer pressures. Market pressures.
Drivers	Increases in information security. Reducing operations cost. Increases in information traceability.
Organizational barriers	Lack of expertise about technology. Lack of tools for blockchain technology implementation. Lack of benchmarking data for blockchain technology implementation.
Supply chain-related barriers	Lack of customer awareness about blockchain technology. Lack of supply chain partner collaboration. Lack of supply chain partner coordination.
Technological barriers	Immaturity of the technology. Limited information technology infrastructure. Security concerns.
External barriers	Market uncertainty about using blockchain technology. Lack of industry involvement in adopting blockhchain technology. Lack of involvement of related communities in adopting blockchain technology.

4.14 Adopting Blockchain Technology

The use of blockchain in business practices is growing in popularity across a number of industries. Maersk uses blockchain technology to track international logistics shipments. Alibaba works with Blackmores, PwC, and AusPost to combat food fraud by utilizing blockchain technology. Walmart uses blockchain to improve productivity and lower costs associated with ensuring the safety of food products (Kshetri, 2018). (Elmessiry et al., 2018) investigate how blockchain technology and artificial intelligence can be combined to address copycat problems in the fashion sector. The authors find that implementing blockchain technology promotes the disclosure of high-quality information and drives up product sales. (Benzidia et al., 2021) explored the relationship between blockchain technology and relational social capital in Industry 4.0 to enhance new product development.

The empirical analysis provides the authors with insights into how implementing blockchain technology can enhance innovation management and provide a secure environment for

information exchange. (Choi, 2022) investigates how operations research (OR) might use blockchain technology to feed risk analysis and optimization (RAO). The author uses the six-step OR technique to address RAO concerns while illustrating how blockchain technology enhances business operations and its adoption. (Zhou et al., 2022) suggested using signaling games to test a company's readiness to use blockchain technology concerning the veracity of the data. The researchers came to that while the quantity of suppliers has a positive impact, the expenses of blockchain and the suppliers' profit harm the retailer's willingness. With its decentralized and distributive structure, blockchain technology is a digital advancement that has a big impact on supply chain management. From production and sourcing to distribution, financing, and consumption, blockchain improves transparency, traceability, and security (Babich et al., 2020; Goyat et al., 2019; Choi, 2020; Dutta et al., 2020).

4.15 Practical Aspects of Implementing Blockchain

Examining a number of factors is necessary when thinking about adopting blockchain. This section goes into great detail about the deployment of blockchain platforms, costs, privacy, and security. Scholars must carefully consider these factors in order to make informed decisions when integrating blockchain.

4.15.1 Permissionless versus Permissioned Blockchains

Companies in the supply chain must choose between using permissioned or permissionless blockchain platforms. Public blockchains, like Ethereum, Solana, and Polygon, offer the advantages of transparency, dependability, immutability, and opensourcing. Additionally, maintenance expenses can be minimal. For example, on the Solana network, transaction costs are only about $0.00025 each, and a public network of validators shares network maintenance. Public blockchains, on the other hand, provide less privacy protection, less scalability, and fewer options for consensus and blockchain governance.

Permissioned blockchains usually offer greater customization options, increased data privacy, and increased throughput and capacity. But because they require a specialized system, they might also come with increased development and maintenance costs. Today, several large technology companies Amazon AWS, IBM Hyperledger, Oracle, and Microsoft Azure, for example offer integrated blockchain services. Permissioned blockchains would be a preferable option overall in this application because real-time production data on the blockchain are primarily used to improve supply-chain efficiency and because companies might not be willing to share the data publicly (Ma et al., 2022).

4.15.2 Security, privacy, and data storage

Since blockchains allow multiple business entities to share data and information, data security and privacy are crucial concerns to take into account. As sharing the data ultimately benefits all parties, the current model allows all players to share data on the blockchain. Nonetheless, circumstances, where information sharing helps a firm's rivals, may occur when there are numerous horizontal players in competition. Building more localized blockchains, such as private channels of blockchains that only consist of specific parties (Hyperledger) or taking into

consideration encrypted data that is accessible to authorized parties are two potential solutions in such a situation.

Blockchain users have the option to store sensitive or large amounts of data off-chain in addition to public shareable information on the chain (with characteristic data like hashes stored on the chain for connection or validation purposes). Since blockchains are now available as a service from significant cloud computing platforms (like AWS and Azure), storing data on the cloud and granting the relevant parties access rights could also be a workable solution (Cao et al., 2019).

4.15.3 Costs and Expenses

Adoption of blockchain will come with costs. Significant upfront investment costs are usually associated with the first adoption; these costs include consultation, design, development, purchase, and installation. Such costs will decrease as blockchain systems evolve to be more uniformly designed. Participants in the supply chain must regularly cover the costs of upkeep and monitoring once a blockchain is put in place. Given that adopting blockchain technology benefits the manufacturer the most directly, it may be more practical for the downstream company to cover the vast majority of the design and development expenses and split the expenses related to upkeep with the upstream suppliers. This is how the Walmart and IBM Food Chain project functions (Nash, 2018).

4.16 Challenges and Barriers in Blockchain Adoption

The adoption of blockchain technology in supply chain management (SCM) encounters multifaceted barriers, as illuminated by several studies. (Avgerou et al., 2020) emphasize the influence of social context on information technology innovation, suggesting that blockchain, as a novel SCM solution, is subject to similar factors that hindered the adoption of previous technologies. According to (Kumar Tarofder et al., 2017), the adoption of the internet for supply chain management is hindered by budgetary concerns, a lack of support from senior management, and a lack of competitive pressure. Similarly, (Asare et al., 2016) highlight the terminal impact of a lack of executive support on new technology adoption, while (Fawcett et al., 2008) note management's uncertainty regarding technology's impact on workforces.

(Balocco et al., 2011) found inter-firm issues, complexity, and cost as key barriers to RFID adoption, a precursor to blockchain, while (Hardt et al., 2017) attributed the lag in QR code adoption to cost, trust, and technical issues. (Saberi et al., 2019) underscored a combination of these factors, coupled with the immaturity of blockchain technology, as obstacles to its operational adoption. (Van Hoek, 2020) emphasizes the poor understanding of blockchain's costs and benefits at the executive level as a barrier to adoption.

Furthermore, the barriers hindering blockchain adoption in SCM span inter-organizational, intra-organizational, technical, and external domains (Saberi et al., 2019). Usability, security, privacy, and cost emerge as significant obstacles (Firica, 2017; Peck, 2017; Choi et al., 2020a), compounded by unclear regulations and high implementation costs (Dutta et al., 2020). (Lohmer et al., 2020) explore barriers through semi-structured interviews with industry experts, highlighting implications for blockchain's development and integration with IoT. (Caldarelli et al., 2021) studied the barriers in sustainable fashion supply chains, categorizing them into technological, organizational, and environmental dimensions. (Liu et al., 2021) identify the lack of standard tools,

methods, and business models as critical barriers, along with functional, psychological, and cooperative resistance (Friedman et al., 2022).

In addition to barriers, blockchain deployment faces challenges, including hardware and energy use, scalability, data adaptability, security, and confidentiality. The development of blockchain hardware accelerators aims to enhance transaction speed and accuracy, while scalability issues persist due to increased exchange costs and user bases. Challenges remain in ensuring data security and confidentiality in peer-to-peer transactions, with high resource requirements and transaction costs hindering deployment. The creation of agile blockchain algorithms may offer solutions to these challenges (Uddin et al. 2023).

In conclusion, the effective adoption and implementation of blockchain technology, particularly in SCM, depends on recognizing and resolving obstacles and challenges. Policymakers, industry experts, and researchers must collaborate to create regulations that promote blockchain innovation and integration while lowering associated risks.

Summary

The chapter explores the origins of blockchain technology, tracing it back to Satoshi Nakamoto's 2008 invention of Bitcoin. It discusses various blockchain models, including public, private, and consortium, and highlights the increasing interest in blockchain across various industries. The chapter also discusses its application in diverse contexts, such as community-owned green energy networks, smart contracts, land registries, and supply chains. It draws attention to the benefits of blockchain technology, which are applicable to a variety of industries and include data security, traceability, transparency, and real-time information sharing.

However, the chapter acknowledges the challenges and barriers in adopting blockchain technology, such as organizational knowledge, supplier cooperation, coordination, customer awareness, infrastructure, technology immaturity, market uncertainties, and concerns related to costs, privacy, and security. It also discusses the decision-making process for companies in choosing between permissioned and permissionless blockchain platforms, weighing the advantages and disadvantages of each option.

The chapter highlights how blockchain technology can automate agreements and transactions while preserving security, efficiency, and transparency in supply chain management through the use of smart contracts. It also highlights the immutability of blockchain technology, which ensures data integrity and transparency, particularly in supply chain contexts where trust in data is essential.

This chapter concludes by discussing how blockchain technology must advance to satisfy the demands of Internet of Things (IoT) devices, especially regarding block size, creation time, and consensus algorithm. The chapter highlights the transformative potential of blockchain technology in changing business procedures and opening up new opportunities for sustainable and efficient operations, despite the difficulties and adoption barriers.

5 Leveraging Blockchain Technology in Supply Chain Management

In this chapter, we will look at the methodologies, results, and implications of incorporating blockchain technology into supply chain management. We'll examine the difficulties and impediments to the adoption of blockchain, as well as successful case studies that demonstrate the technology's potential. In addition, we will look at how blockchain can help with supply chain sustainability, transparency, and efficiency. Using an academic perspective, we seek to offer a comprehensive understanding of blockchain technology's multifaceted implications in reshaping the landscape of supply chain management.

5.1 Blockchain in Supply Chain

Across several industries, blockchain technology is now a disruptive factor, providing creative answers to difficult problems (Queiroz et al., 2021). Blockchain technology has generated a lot of curiosity in the supply chain management (SCM) because of its ability to improve efficiency, traceability, and transparency (Saberi et al., 2019). Enhancing cost, quality, speed, dependability, risk reduction, sustainability, and flexibility are the supply chain's traditional goals. These goals ought to be easier to accomplish with blockchain technology and more dependable transactional records (Di Vaio et al., 2020).

Blockchain technology has the ability to completely change supply chain and logistics as well as many other economic sectors' business models. Many supply chain issues, including real-time communication, establishing trust between partners, fostering secure relationships, processing payments more quickly and with fewer transaction fees, lowering product costs, cutting lead times, improving forecasting, removing bottlenecks, and conserving and recycling resources, could all be helped by blockchain technology (Casado-Vara et al., 2018; Saberi et al., 2019; Kouhizadeh et al., 2018).

The potential of blockchain technology to improve transparency in the supply chain is among its most important advantages. Blockchain technology guarantees the optimal transfer solution and makes network resource management, traceability, transparency, and security easier. Supply chain operations become more traceable when blockchain is integrated with IoT devices like RFID, laser scanners, and sensors. Every two seconds, during logistics operations, this system records the temperature, humidity, speed, and location of the vehicle and uploads the information to a cloud-based platform. In just two seconds, patrons can locate the food's origin with ease (Queiroz et al., 2019; Saberi et al., 2019; Pournader et al., 2020; Li et al., 2021).

An increasing number of studies have been conducted regarding blockchain technology and its potential to improve supply chain visibility. These studies can be divided into two categories: academic studies that conceptualize blockchain for supply chain visibility and industry studies that offer real-world examples of blockchain applications in use. Supply chains may now function more efficiently while also spending less money, wasting less time moving goods through the system, and managing waste better thanks to blockchain technology (Kshetri, 2018; Saberi et al., 2019; Apte et al., 2016; Tian, 2018).

Numerous earlier studies have covered the various facets of blockchain technology-based supply chain. For instance, transparent transactions within the blockchain network were covered by (Tapscott et al., 2017). Blockchain's adopting factors and sustainable relationship were demonstrated by (Saberi et al., 2019). But the authors also noted the difficult factors that require further research in order to bolster the blockchain's success factors. Additionally, the adoption of blockchain technology in organizations was covered in earlier studies. (Pournader et al., 2020) and (Li et al., 2021) investigated the application of blockchain technology in the aviation and supply chain sectors in this regard. For instance, it streamlines the procedure and provides an affordable solution. In his research on the "adoption of blockchain technology," (Mobi, 2020) stressed that supply chains become more transparent, seamless, efficient, and economical when parts and information are shared with stakeholders. Blockchain technology is also being adopted by the logistics sector because it promotes information sharing and transparency (Queiroz et al., 2019; Saberi et al., 2019).

Ensuring the dependability and transparency of the supply chain is of equal importance for intermediate suppliers, as distribution center management might increase their trust in the supply's dependability by looking at previous transactions. The issues of supply chain management optimization and improvement are also relevant and in demand due to the escalating rivalry in the market for logistics mediators and the requirement for fresh, innovative approaches to working with digital technologies. The potential of digital technologies to drastically change the supply chain management industry's present organizational and financial practices. The traditional supply chains' numerous operational problems and delays can be avoided by switching to digital supply networks, which are dynamic, interconnected open supply systems. In these networks, information flows are constant and easily accessible to all network users. The blockchain is one of these contemporary digital technologies (Uddin Et al., 2023).

With notable successful use cases from IBM, Walmart, and Everledger, there has been an increase in the prevalence and interest of focal firms in adopting blockchain technology to improve sustainable supply chain performance in recent times. Being a leader in this field, IBM has tried to use blockchain technology in the supply chain. In order to track the origin of pork in China and its production in the United States, Walmart tested distributed ledger technology. Everledger aimed to end the use of forced labor in Africa and bring greater transparency to the diamond supply chain through the deployment of blockchain technology.

The technology itself can be adopted in a variety of ways, or it can serve as the basis for other tools like cryptocurrency. Due to the fact that blockchain technology is still relatively new and is among the most widely used innovations in the information sciences, it is difficult to accurately predict the performance of blockchain technology prior to implementation. Supply chain transparency may result in mutually beneficial outcomes and competitive advantage driven by blockchain technology. No evaluation technique has used transparency of information, processes, or products as a primary criterion. As a result, we investigate this area, outlining how blockchain affects supply chains and how it can be quantified. (Casado-Vara et al., 2018; Saberi et al. 2018a; Kouhizadeh et al., 2018; Tapscott et al., 2017).

In conclusion, by improving transparency, traceability, and efficiency, blockchain technology has the potential to completely transform supply chain management. It may be used to fix a lot of supply chain problems, including real-time communication, establishing trust between partners, creating secure relationships, processing payments more quickly and with fewer transaction fees, lowering the cost of products, reducing lead times, improving forecasting, removing bottlenecks,

and conserving and recycling resources. To increase the success factors of blockchain, it is necessary to look into some difficult factors as well.

Organizations can adopt blockchain technology to expedite procedures and offer an affordable fix. While supply chain blockchain technology is still in its early phases of development, interest in applying it to improve sustainable supply chain performance is growing (Saberi et al., 2019; Tapscott et al., 2016; Christidis et al., 2016; Hofmann et al., 2017; Queiroz et al., 2019).

5.2 Role of Blockchain in Supply chain

The Fourth Industrial Revolution has given rise to cutting-edge technologies like blockchain (Grover et al., 2019; Olsen et al., 2020) It has the potential to digitize SC greatly since it contains features like data immutability, operations consistency, keeping records, and a consensus process that creates a reliable business environment based on cryptographic evidence with few or no middlemen (Tandon et al., 2021; Moosavi et al., 2021). In particular, blockchain runs on a distributed ledger database that is highly secure and real-time, enabling information sharing between SC partners and enabling them to follow the product assembly process from the point of procurement to the end user (Sahoo et al., 2022).

5.3 Example for the role of blockchain in supply chain

Blockchain has powered the global distribution of COVID-19 vaccines, giving manufacturers the ability to proactively monitor vaccine delivery and handle unfavorable incidents (like drug recalls), as well as fostering consumer confidence in the traceability of the vaccines they receive. In this sense, blockchain gives every SC member instant access to information about SC activities, which enhances inventory control and strengthens SC problem-solving. More importantly, as SC participants within the world become more integrated within its use, integrating state-of-the-art ICTs like blockchain in SSCM may address not only the obstacles to transparency and traceability in SC but it can also promote coordination and enhance transparency (Sahoo et al., 2022; Mbunge et al., 2021).

Product labeling solutions provide a degree of visibility that wasn't previously achievable, and they all work in tandem with and enhance blockchain solutions. For instance, when it comes to product recalls, "retailers currently have a challenge figuring out where harmful substances arrived from and to which locations they were provided" in case of a foodborne illness outbreak. Current systems are vulnerable to manipulation because goods cargoes presently require a lot of paperwork.

In a traditional supply chain, the replacement of documents may go undetected because there is too much paperwork to review on a regular basis and because different products may have the same appearance. For example, it can be difficult to identify mislabeled fish because different species may not be visually identifiable. This could be addressed by a blockchain-enabled system that adds unit-level visibility to traceability, making fraud and counterfeiting more challenging. Through the secure storing and compilation of data on each unit, blockchain accomplishes this "

“by offering a practical means of tracking custody, confirming authenticity, tracing origin, and ensuring product integrity " (Montecchi et al., 2019; Kshetri, 2018; Rogerson et al., 2020).

Food supply chains are thought to be susceptible, and US retailer Walmart is the most well-known blockchain case in the literature. Tracking pork in its Chinese supply chains at first, the company feels that blockchain's increased visibility ensures improved risk management and sourcing control: "Even in the case of pollution, the greater controls and visibility provided by Blockchain enable the contamination to be tracked to the source for proper corrective actions." Blockchain may also help to reduce other food-related risks. The $15 billion annual cost of counterfeit wine, or 5% of the global market, proves that supply chains require the visibility that blockchain technology can provide. To ensure that information is exchanged solely with a limited number of partners in this case, the entire supply chain from vineyard to retailer the proposed system uses a consortium protocol.

By entering the product ID into the system, anyone working in the supply chain can trace the origin and verify the provenance of the wine they have purchased, production, and purchase history of each product. The system first determines the wine batch after obtaining the product ID, and it then tracks back all of the transactions made for that item by various supply chain participants (Biswas et al., 2017)

Fraud of this kind is not exclusive to more expensive goods like wines. A similar idea is developed by (Rejeb, 2018) for Ghanaian tilapia, a white fish that is frequently misrepresented. The plan is to record using mobile technologies farm-level environmental conditions on a blockchain, which is then used to track products through the supply chain using RFID tags, providing the consumer with visibility into the product's origin (Rogerson et al., 2020).

5.4 The Importance of Blockchains in Supply Chains

5.4.1 Transparency, authenticity, trust, and security

Participating companies can benefit from transparency through blockchain-enabled transactions, which are a series of transactions necessary to move a product from one location to another. For instance, every transaction involving the production, distribution, and sale of a product could be recorded in a block. This degree of openness and visibility is necessary to guarantee the products' legitimacy and authenticity as well as to enhance their traceability. Blockchain technology has the potential to be linked with RFID tags and the Global Positioning System (GPS) to provide real-time tracking. Unlike the conventional method of using a third party, records of transactions and other activities are available for every participant to access since every record recorded in a blockchain is shared between all network members (Abeyrante et al., 2016).

Each individual has access to similar information inside the system and can check the products' location and progress. This increased visibility offers an auditable trail of a product's footprint, which is especially appealing to sectors where a product's provenance is critical. This feature might increase buyers' trust in suppliers. Building trust in the supply chain also depends on the transparency provided by blockchain technology, which has the potential to completely change how we think about and study supply chain trust. In the past, intermediaries and mechanisms like banks and endorsed documentation played a crucial role in mediating transactions between organizations to establish essential trust among supply chain actors (including sellers and buyers) (Field, 2017; Loop, 2016).

Because there was often little visibility and transparency among these supply chain participants, especially in multi-tier supply chains, there was a tendency for trust to be low. Building trust in supply chains frequently required long-term financial and relational commitments. But with blockchains, the technology platform itself is built with trust preinstalled. Some argue that in this "trustless" environment, supply chain operations can be carried out without the need for onerous processes aimed at fostering trust between organizations. Blockchains can also be very helpful in preventing fraudulent transactions and recovering stolen goods. Blockchains may be used in supply chains for additional reasons, including increased security since they guard against fraud, tampering, and cybercrime. Authenticity and reliability need to be proven to attain security. These characteristics use the form of data integrity, which is a crucial feature of ledgers based on blockchain technology.

Once data is incorporated into a linear chain, it cannot be changed within a blockchain. pointed out that "permissioned" blockchains are especially valuable to businesses because they offer enhanced privacy, audibility (because a shared ledger that serves as a single source of truth improves the ability to monitor and audit transactions), and increased operational efficiency (because transactions can be conducted at a speed more in line with the pace of business). The technology's distributed consensus characteristics, which allow for the storage of only one true, verified version of the data among all members of the network, are responsible for this immutability (Wang et al., 2019).

5.4.2 Efficiency and cost/waste reduction

Using blockchains could increase supply chain and logistics efficiency because the technology speeds up data streams being transferred between parties. As a result, they might shorten the time goods spend traveling, enhance inventory control, and eventually cut costs and waste. As was previously mentioned, one of the main tools for increasing supply chain efficiency is smart contracts. Writing smart contracts requires the use of programming code languages and is fully digital. A smart contract's terms and conditions are outlined in the same manner as they would be in a conventional legal document, including the benefits, penalties, and obligations.

A blockchain system can carry out the contracts automatically, greatly automating and streamlining supply chain operations. They are especially helpful in more intricate multi-vendor outsourcing contracts where multiple suppliers share accountability for a specific result. Blockchain technology goes beyond simple matching to enable threshold-based payments, replenishment, aggregation programs, and more by enabling the cascading of orders of purchase, bills, change orders, receipts, ship notifications, and other trade-related documents and inventory information throughout a supply chain. Participants in the supply chain can learn more about customer preferences and the level of demand for specific products with enhanced data visibility. These skills can assist organizations in making better decisions and planning more precise demand forecasts.

Efficiency can be increased by digitizing document transfers and speeding up data flow, especially when it comes to cross-border operations. For instance, in the shipping industry, Maersk discovered in 2014 that a straightforward shipment of chilled goods from East Africa to Europe may involve nearly 30 parties and over 200 interactions and communications between them. This is a drawn-out process that is prone to mistakes, delays, and the duplication of records and

information submissions. To tackle this issue, Maersk and IBM worked together to create a cross-border blockchain-based solution that aims to enhance workflow and provide real-time visibility into the status of each shipment. The system should allow trading partners to share highly secure information.

The proposed solution may help shippers save money on trade documentation and processing fees, as well as minimize delays brought on by mistakes made when moving paperwork physically. Shipping containers will also be visible through the system as they move forward in the supply chain. In order to greatly improve the information accessible for risk analysis and targeting, the solution is meant to give customs authorities real-time visibility. This could ultimately result in increased safety and security as well as more efficiency in border inspection authorization processes. Blockchains also allow for faster tracking, which can cut down on the amount of time it takes to complete a tracking task from days to minutes.

Efficiency can be attained through preventive measures in addition to eliminating inefficient activities from the supply chain. For instance, (Kharif, 2016) makes the case that blockchain projects could be used to track food safety, as well as to lower operational costs by reducing waste and spoiling. Two further benefits of paperless transactions are decreased environmental impact and improved inventory management without the need for double verifications (Field, 2017; Release, 2017; Loop, 2017).

5.5 Implementing blockchain technology in the supply chain

It's important to remember that supply chain blockchain integration is an ongoing process that requires patience and refinement. It requires extensive planning, close company cooperation, and knowledge of the possible long-term advantages. However, blockchain technology has enormous potential to change the traditional supply chain environment into one that is more competitive, dependable, and efficient if the proper conditions are met. Many businesses and organizations have begun incorporating blockchain technology into their supply chains in recent years. These businesses are aware of the enormous potential blockchain presents for enhancing productivity, reducing expenses, and boosting confidence among all stakeholders.

An important advantage of blockchain technology is increased supply chain transparency. All parties involved, from producers to consumers, have access to information about the creation, delivery, and distribution of goods. As a result, there is improved process visibility, enabling supply chain participants to react to changes faster and more effectively. Furthermore, each product's origin and history can be documented thanks to blockchain's capacity to securely and verifiably create transaction records. It is simple for customers to confirm that the goods they purchase are authentic and originate from reputable producers. This promotes consumer confidence in businesses and brands while lowering the flow of fake goods. Smart contract implementation is another crucial component of supply chains driven by blockchain technology.

Automated protocols known as "smart contracts" allow agreements to be carried out under specified conditions. Smart contracts are able to be employed in supply chains to more accurately and efficiently arrange and track payments, shipments, and inventory. As a result, the transaction process experiences less bureaucracy and human error. Blockchain technology's incorporation into the supply chain presents a number of obstacles that must be addressed. To establish a

cohesive ecosystem, businesses and other supply chain participants must work closely together. To be used at scale, blockchain technology must also be able to handle enormous volumes of data quickly and effectively. Consideration must also be given to important aspects such as modifications to corporate culture and business processes.

Implementing blockchain technology within the supply chain might necessitate modifications to the current operational framework. Thus, for an implementation to be successful, knowledge and encouragement from stakeholders inside the company are essential. There is great potential for blockchain technology to improve supply chain effectiveness and opening the door to a more open, safe, and effective system. Businesses can embrace these changes and move toward a more inventive and connected future by comprehending the obstacles and implementing appropriate plans (Rahima et al., 2023).

5.6 Blockchain deployment in the supply chain

Blockchain has disrupted and continues to disrupt a wide range of industries, including finance, operations, real estate, insurance, healthcare, electronic health records, copyright, music, renewable energy, and supply chains. This is because blockchain is decentralized, verifiable, and immutable. Even though at first, blockchain was primarily used for financial applications and crypto currencies (Crosby et al., 2016), The non-financial sectors were driven to adopt this "game-changer" due to the revolutionary qualities of blockchain (Johnson, 2018). To improve supply chain capabilities in real time, applications of blockchain technology are beginning to change a number of aspects of operations and supply chain management (Saberi et al., 2018; and Oliveira et al., 2019).

Implementing blockchain technology in the supply chain can lower costs and mitigate risk while enhancing sustainability, speed, flexibility, and quality. Blockchain is an innovative technology for supply chain management (SCM) and is more than just a catchphrase. It can have a big impact on business organizations (Queiroz et al., 2019). Numerous benefits of blockchain technology could assist a lot of Supply Chain Management (SCM) problems (Kshetri, 2018).

Previous studies looked at the potential of blockchain technology in SCM with regard to four main areas: trade, technology [IoT, RFID], traceability and transparency (Pournader et al., 2020). Adoption patterns and the application of blockchain technology in the supply chain were examined by researchers. Improved demand forecasting, inventory management during the planning stage, product traceability, risk and disruption management, and trust-building during the coordination stage are some of the potential SCM applications of blockchain technology (Saberi et al., 2018; Hofmann et al., 2018).

Additionally, researchers looked into how blockchain technology might be used to leverage a range of supply chain functions, including supply chain distribution, resilience, inventory management, resilience forecasting, and order management. According to (Van Hoek, 2020), supply chain businesses must decide which particular supply chain goal they hope to accomplish by implementing blockchain technology. Supply chains benefit most from blockchains because of their increased visibility and traceability of products. Maersk, Provenance, and Walmart are among the companies looking to integrate blockchain technology through the supply chain processes to enable product traceability. Supply chain coordination is facilitated by blockchain-

based traceability, which also improves quality control and lowers production costs by improving forecast accuracy (Madhani, 2021).

Inventory control and data reconciliation can both be accelerated and enhanced by using blockchain technology for traceability via automated transactions. Since a consensus mechanism is used to distribute information in real-time between peers, less information asymmetry may discourage supply chain participants from engaging in rent-seeking activities. Suppliers would have a better understanding of demand information thanks to this increased information flow, which would improve their ability to forecast lead times and lessen the "bullwhip" effect. Blockchain technology helps address the primary problem of data visibility by putting a check at every step, from warehouses to consumers (Awwad et al., 2018; Francisco et al., 2018).

Blockchains record information about an asset's location at any given time, its ownership or custodianship, and its transactional history (Ølnes et al., 2017). By maintaining verifiable and trustworthy data about previous transactions, blockchain can improve supply chain transparency and visibility (Wang et al., 2019). By giving all parties involved in the supply chain access to information about its operations such as enabling customers to assess products before making a purchase blockchain improves supply chain transparency. The adoption of blockchain technology in supply chains has been found to be facilitated by transparency (Kamble et al., 2018; and Wamba et al., 2020).

The immutability, transparency, and security that blockchain technology offers makes it a viable answer to the problems with trust and traceability. Some blockchain applications have also set out to minimize the amount of counterfeit goods. In the agri-food sector, blockchain is also used to track the origin and manufacturing process of food ingredients, demonstrating its usefulness in tracking the provenance of goods across intricate supply chains.

Blockchain is used by Chipotle Mexican Grill to ensure food safety. A theoretical framework for an RFID-integrated blockchain-based agri-food supply chain tracking system is put forth by (Tian, 2017). Pharmaceutical supply chains may track temperature and humidity during the transportation of medical supplies when blockchain technology is combined with IoT. According to (Mackey et al., 2017), a blockchain will make it possible to track pharmaceutical raw materials and final products, which will facilitate the detection of fakes by enabling blockchain participants to authenticate data. By implementing a blockchain platform identified as "Tracr" to verify origin, authenticity, and traceability along the whole value chain, De Beers was able to track diamonds with success.

Through the use of ID inscriptions, the De Beers Group's "Tracr" initiative seeks to track diamonds on the blockchain. An accessible platform for all industry participants in the diamond value chain is proposed by the initiative. De Beers could obtain more global insights into diamond moves and sales by opening the system to all participants. Crisis situations in manufacturing supply chains, such as product recalls following the discovery of security and safety flaws, can be managed by technology. According to (Lee et al., 2017), the implementation of blockchain technology in the consumer electronics supply chain improves transparency and process integration. Blockchains have the potential to impact supply chains in a number of ways, including providing a digital identity for ownership and packaging, a tamper-proof history of the product's manufacturing, handling, and maintenance, engagement with consumers, and smart contract-based supply chain tendering.

The implementation of smart contracts and sustainability in the supply chain are further advantages of blockchain technology in the supply chain. (Min, 2019) offers suggestions for using blockchain and smartcontracting to control supply chain risk in the context of the order fulfillment process. Blockchain creates trustless environments by providing immutability, transparency, security, trust, and computational logic, all of which reduce the need for middlemen. Sometimes, blockchain technology is called as "the trust machine" because it solves trust-related problems and offers a way to reduce the need for trust during transactions, which makes it ideal for use in supply chains (Madhani, 2021).

Trust, cost savings, automation, processing speed, simplified procedures, and disintermediation are some possible advantages of blockchain technology. Disintermediation boosts trust and speed among supply chain participants. Multiple supply chain participants can conduct transactions with one another through the blockchain without the need for a middleman. Members who participate are motivated to collaborate and are encouraged to do so by this shared value. To improve food safety and traceability by offering reliable information on the origin and condition of food, Walmart, JD.com, IBM, and Tsinghua University are collaborating on the deployment of blockchain technology. Blockchain technology also makes it possible for rival organizations to join the same network. For example, IBM Food Trust has several retailers involved.

The use of blockchain technology increases cost savings that are primarily attained by removing process middlemen and avoiding fraud or legal expenses. The aforementioned advantages have led numerous corporations, such as Walmart and Glencore, to incorporate blockchain technology through their supply chains to enhance productivity and effectiveness. Three key areas are being addressed by the deployment of blockchain technology: disintermediation, reduced transaction costs, and verified traded goods (Madhani, 2021).

Supply chain side issues like supply chain architecture prescriptions, supply chain user attitudes, supply chain sustainability, supply chain resilience, and supply chain performance have also been the subject of prior blockchain research (Min, 2019). To manage the processing and storing of substantial volumes of "decentralized" supply chain transactions, (Gao et al., 2018) suggest a two-layered blockchain-based supply chain system.

(Hald et al., 2019) conclude by talking about how blockchain affects supply chain performance, both positively and negatively. The effects of blockchain technology on supply chain integration and the obstacles associated with its adoption are examined by (Queiroz et al. 2020). (Gausdal et al. 2018) talk about the adoption of blockchain-based supply chain systems and the factors that encourage adoption (like regulation and cost reduction) and hinder it (like implementation costs, internet speed, and innovation diffusion). According to (Kamble et al., 2019), supply chain managers are more likely to adopt blockchain due to its regarded usefulness and simplicity of use.

5.6.1 Examples of Blockchain deployment in the supply chain

On September 4, 2017, South Korea's Hyundai Merchant Marine (HMM) declared that it had effectively finished its first trial voyage utilizing blockchain technology for cargo delivery, shipment booking, and real-time container monitoring and management (HMM, 2017). Walmart claims that blockchain trials have aided the company in the food industry, cutting the time it takes to track the movement of a mango shipment from seven days to 2.2 seconds (McKenzie, 2018). By the end of 2018, a group of businesses in the energy sector, including BP and Royal Dutch Shell, intend

to create blockchain-based digital platforms for trading energy commodities. Blockchain technology has been used in the diamond industry to guarantee the authenticity of the stones and in cross-border trade to reduce the complexity of workflows. Most of the previously mentioned projects use permissioned blockchains, to which only specific supply chain participants have access (Wang et al., 2019).

In the food and transportation sectors, in addition to many other industries, including healthcare (Pfizer and Change Healthcare), energy (Shell and Siemens), banking and finance (Visa and HSBC), travel (Delta Airlines and British Airways), insurance (MetLife and Prudential), and even government (Seoul Metropolitan Government and Monetary Authority of Singapore), a number of companies, including Ford and Unilever, have been implementing blockchain technology in their supply chains (Park et al., 2021).

5.7 Blockchain for Supply Chain Management

The blockchain is a list of append-only blocks, each containing several pieces of data, that are maintained by a peer-to-peer network that follows a set of rules for communication between nodes. The consensus mechanism, or protocol for validating new blocks, is what gives blockchain its magic. After verifying the data in the block, the majority of nodes will concur via a consensus algorithm that each block exists. Since the majority of nodes on the blockchain will not acknowledge it, it can be very challenging to alter the data. Different application scenarios are targeted by different types of blockchain systems, such as permissioned and permissionless blockchains.

The characteristics of data immutability and system decentralization are brought about by the nature of blockchain technology. These characteristics offer possible ways to meet supply chain data management requirements. First off, information cannot be readily altered and is regarded as trustworthy evidence of existence since the blockchain is being used to store and control the data circulation in the supply chain. Second, rather than being kept separately in separate systems, data from various supply chain stakeholders can be incorporated into the blockchain system, facilitating data sharing and saving money and time on data retrieval. We shall present the current efforts to use blockchain for supply chain management in the following section (Wu et al., 2019).

5.8 Blockchain technology and supply chain management: An Overview

The advent of Industry 4.0 enabling technologies is drastically altering modern supply chains. Supply chains are evolving into incredibly complex systems, managing both new and existing partners while being geographically dispersed and narrowly focused on meeting the needs of ever-more-demanding customers, according to (Saberi et al. 2019b). At the same time, transparency and traceability have emerged as essential needs in an international supply chain. Blockchain technology can help address concerns related to Sustainability in the social, economic, and environmental spheres as well as help create supply chains with strong traceability and transparency features (for example, by utilizing cutting-edge RFID and GPS technologies).

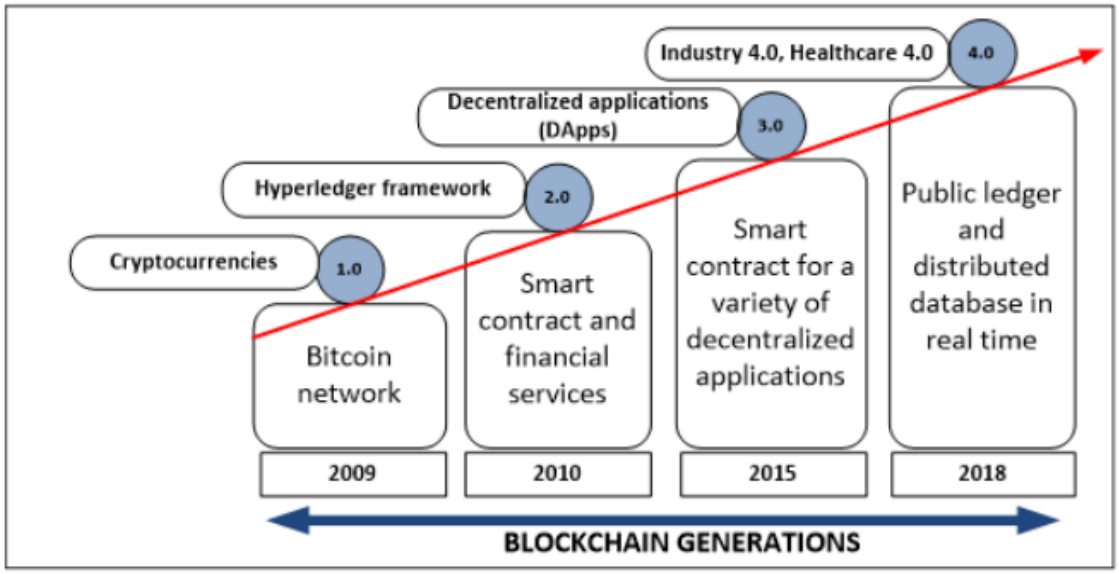

Figure 5. Blockchain evolution. (Buthelezi et al., 2021)

As seen in Figure 5., blockchain technology has advanced from generation 1.0 to 4.0 since Satoshi Nakamoto introduced Bitcoin technology in 2009. The first iteration of the blockchain was the cryptocurrency. The goal was to make it possible for digital transactions to be carried out more quickly and securely over a blockchain network than they could be through a conventional banking system. The most well-known and initial use of blockchain 1.0 is Bitcoin. Smart contracts, which use self-executing codes to validate transactions, were first introduced by Blockchain 2.0.

Two examples of blockchain 2.0 platforms are the Ethereum platform that (Buterin, 2013) proposed and the Hyperledger Fabric framework that the Linux Foundation (2017) developed. Both Ethereum and Hyperledger Fabric are community-driven, open-source blockchain platforms that aim to offer a reliable collection of frameworks, libraries, and tools for building blockchain applications. Decentralized applications (DApps), which are used to prevent transactions from going through a centralized infrastructure, are associated with Blockchain 3.0. By building on the foundations set by earlier blockchain generations, blockchain 4.0 refers to the methods and solutions that make blockchain technology adaptable to business needs.

Because many organizations are using smart technology to automate traditional manufacturing, data exchange, industrial practices, and processes, they can overcome the obstacles posed by the Fourth Industrial Revolution (4IR) with the aid of Blockchain 4.0. In this instance, blockchain offers a reliable and safe platform for automating business procedures and data exchange. Healthcare, the Internet of Things (IoTs), and supply chain management are a few industries where blockchain technology satisfies 4IR requirements. Blockchain's potential to revolutionize digital service delivery, data management, and value exchange has been extensively discussed since the widespread adoption of the Internet (Chamola et al., 2020; Buthelezi et al., 2021).

Recently, there has been a focus on blockchain technology as a potential solution for the increasingly complicated supply chain management issues. SCM is composed of several closely connected, sequential processes that involve manufacturers, suppliers, distributors, retailers, and customers. SCM also covers the planning, organizing, and administration of products and/or

services. However, there are still a lot of issues with the traditional SCM procedures, like handling transactional information and data, stakeholder mistrust, and opaque supply networks. Paper methods and/or centralized databases have been the mainstays of traditional SCM transaction tracing techniques.

The integrity of supply chain records management has been impacted by these two approaches, which have frequently led to errors and data manipulation. IoT technologies, like barcodes, smart tags, RFID, and Wireless Sensor Networks (WSN), were introduced to track products in supply chain management. These technologies also help the supply chain management industry resolve data integrity problems. However, there are still issues with IoT device vulnerability regarding content modification, cloning, counterfeiting, and fraudulent behaviors. For instance, it is possible to get around the security of RFID tags, which opens up new security holes. SCM networks are becoming more and more global, technological, and geopolitical. Political unrest, barriers to trade, violence, graft, theft, criminal activity, and piracy are the geopolitical dimensions (Duan at al., 2020; Rejeb et al., 2019; Buthelezi et al., 2021).

Market demand shocks, price swings, border interruptions, fluctuations in currencies, and energy shortages are some of the economic obstacles. Infrastructure breakdowns and technological disruptions are two of the biggest global SCM challenges. Any of these use cases can benefit from the use of blockchain technology: (a) There are two or more stakeholders involved; (b) There may be intermediaries that could be removed to improve the efficacy of the system; (c) Trust between the involved entities is necessary; (d) Data integrity needs to be maintained; and (e) Transparency and openness are necessary, as well as the need to foster trust among the cooperating stakeholders. The characteristics of SCM transactions are as follows. As a result, blockchain may improve SCM procedures.

Blockchain technology enables the tracking of products within the supply chain management network, from the manufacturer to the end user. Transparency and openness are ensured by the blockchain's concept of copying information across all network nodes. Blockchain technology's tracking and tracing capabilities allow supply chain management (SCM) stakeholders—particularly consumers—to determine if the product they consume has been tampered with. For instance, the blockchain platform VeChain was utilized in the Cyprus pharmaceutical Supply Chain Management to track COVID-19 vaccination doses and stop counterfeiting (VeChain, 2018). Recalls of products are also decreased by traceability (Wang et al., 2020).

Another intriguing aspect of blockchain technology is decentralization, which allows for the replication of ledger data across several network nodes so that the demise of a lone blockchain network node has no effect on the ledger's state. Blockchain features called self-executable smart contracts improve the way transaction agreements are enforced. In addition, no record kept on the network can be changed due to the blockchain's immutability feature (Buthelezi et al., 2021).

5.9 Leveraging Blockchain Technology for Enhanced Supply Chain Management: A Brief Overview

A supply chain can be conceptualized as a deliberate, methodical network that produces and delivers a specific product to the final consumer to reduce costs and maintain market competitiveness. It consists of numerous information flows, processes, and other elements in

addition to people, organizations, and other resources. The supply chain is the route taken by a product from its point of origin to the ultimate consumer. The provision of materials for their fabrication, market transportation, and delivery to the final customer are the first steps in this process. Five parties are involved in supply chain operations: distributors, manufacturers, marketers, and customers. Every link in the supply chain carries goods to another link under the terms and payment agreements agreed upon (Sunny et al., 2022; Chang et al., 2022).

These agreements, payments, and shipping procedures are supported by blockchain technology by employing contemporary supply chain management techniques. Faster production cycles and lower costs are dependent on well-optimized supply chain processes. Moreover, the supply chain management system is composed of a vast array of tasks spanning numerous domains. In order to proceed and grow, manufacturers are trying to identify solutions for the numerous issues they face. It is now imperative for manufacturers to achieve their objectives of gaining social and economic benefits while maintaining environmental-friendly practices.

Development of sustainability enables manufacturers to successfully adjust to various issues. The typical manufacturing supply chain uses a centralized strategy to control and store the data in a single location. Because centralization increases the risk of data loss, which may erode chain of supply participants' trust in one another, the entire system is therefore vulnerable to error, security breaches, corruption, or attack. Sufficient reliability and transparency in supply chain goods and procedures are also necessary for the centralized manufacturing supply chain. Strengthening the current supply chain is necessary in terms of transparency, information security, dependability, and accountability in order to inspire confidence and maintain it.

Blockchain technology supports sustainable manufacturing practices by establishing a transparent, secure, transparent, and reliable supply chain. This allows one to observe the effects of blockchain technology in the ethical, ecological, financial, and economic pillars of sustainability. Typically, completing the product lifecycle is a basic sustainability objective that can be more easily attained with blockchain technology. Data collection, data analysis, and decision-making are the three fundamental categories that technology competencies fall under them. The use of blockchain technology has mostly been experimental when it comes to industries other than finance. In supply chain management, blockchain technology is expected to have some of its most promising non-financial uses (Liu et al., 2023; Gürpinar et al., 2021).

These sectors present excellent opportunities for applying blockchain technology and will most likely see early returns on blockchain deployment. Using blockchain technology in an SCM environment is probably going to cause disruptive changes in every industry. As a result, the decentralization of the transactions is already altering traditional relationship models. Transparency in product delivery operations is a critical issue for customers at all levels, as it is generally difficult to track every instance. Specifically, because we have no control over the full network of vendors, marketers, transporters, storage facilities, and other suppliers, the majority of end users are ill-informed about the goods they purchase and utilize (Uddin et al., 2023).

5.10 Application of Blockchain in Supply Chain Management

There are multiple stages and locations involved in the delivery and production of goods because they involve multiple points. Supply chain networks face a number of difficulties, including those

relating to performance monitoring and transparency. These may lead to a number of issues, such as miscommunications between organizations. Customers value product and goods tracking, and these issues can pose serious challenges when it comes to quality and condition monitoring, for example.

A key component of supply chains is quality management. Supply chain networks become more efficient when data is distributed quickly between various organizations because it fosters transparency between them. Transparency and security for logistics are provided by using blockchain, which is thought to be a good solution. Even with basic applications, blockchain technology offers great traceability features for logistics (e.g., goods and different items). There are multiple methods for tracking products and services.

Because blockchain is a technological platform, any organization involved in the supply chain can participate. Because of the unchangeable technology of blockchain, security is also at an exceptional level. Using a chronological order of transactions validated by an exclusive spendable crypto-digital currency, including bitcoin, a technology like blockchain further enables the achievement of real-time granular visibility, guarantees trust, and enforces security.

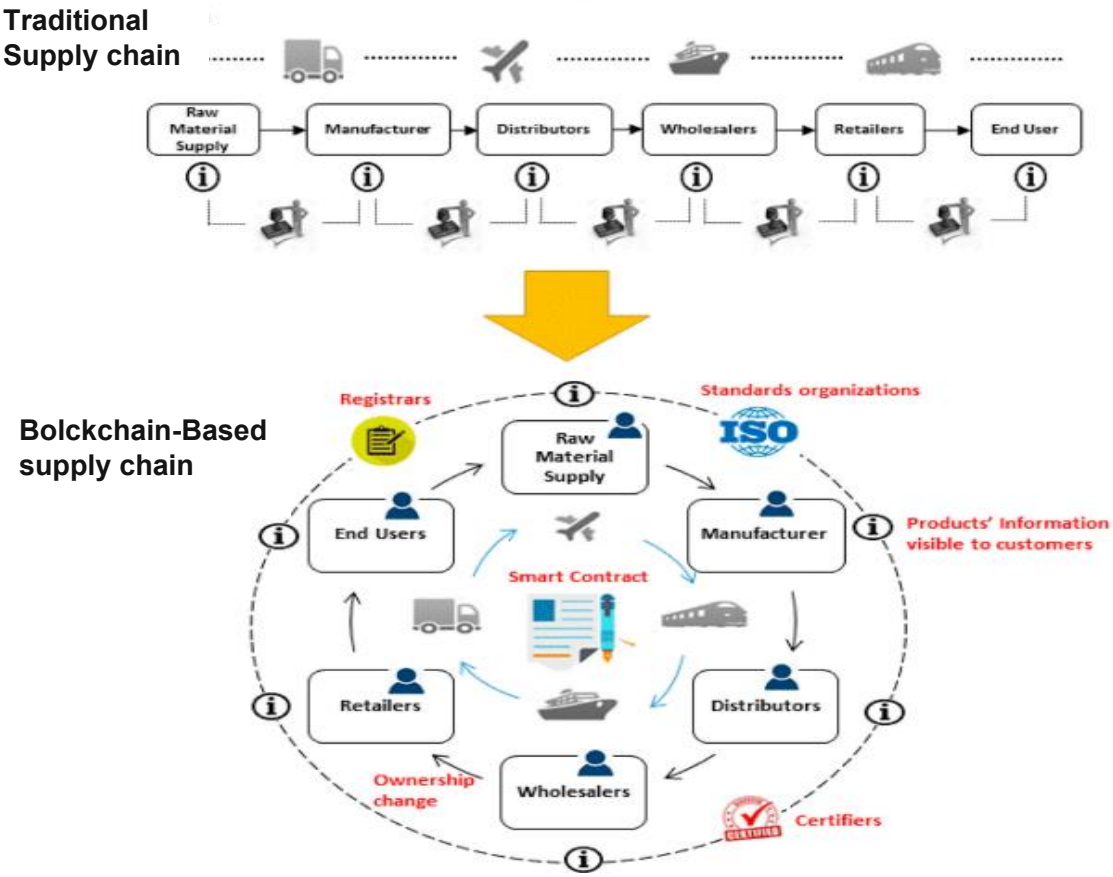

Figure 6. Supply chain transformation. (Saberi et al., 2019)

As we can see Fig 6. shows supply chain management based on blockchain technology and traditional methods, respectively. As can be seen from the Figure 6., in traditional supply chain networks, the manufacturer, distributors, wholesalers, retailers, and consumers come first in the

supply chain hierarchy. Information is transmitted in a sequential manner from suppliers of materials to end users. Six significant players that are absent from a traditional supply chain network are involved in a blockchain-based supply chain network.

The six entities include product delivery with quality certifications, authentication, visualization of product information, registration, standard maintenance, and ownership transfer. Every participant in the supply chain receives a unique identification through the registration process, and the maintenance of a standard entity guarantees that the products are supplied in accordance with blockchain regulations and technical specifications. As seen in Figure 6., all pertinent data about the products that are supplied is displayed along with the required authentication procedure.

Ownerships are transferred between supply chain participants, such as manufacturers, retailers, and customers, in a blockchain-based supply chain (Saberi et al., 2019). Consumers receive finished goods accompanied by quality certifications from accredited organizations (Sivula et al., 2021).

Every product in blockchain-based supply chains might have a digital identity to guarantee direct product profile access for all pertinent supply chain participants. With the right digital keys, this product identification process offers the security precautions required to access a product. According to (Abeyratne et al., 2016), this digital key functions as an information tag that is affixed to a product and serves as a link between physical products and their virtual identities in the blockchain.

A digital contract between the two actors in the supply chain may be required to access the product profile and send or sell the goods to a different actor. The digital sign is overseen by a smart contract, which secures the required authorization through agreements and consensus among supply chain participants. Smart contracts support the upkeep of communication within the system and between the participants in the supply chain. Smart contracts support continuous process improvement and network data sharing among supply chain participants.

Smart contract governance and procedure rules can provide certification and approval to supply chain actors, thereby managing them in a blockchain-based supply chain. The aforementioned certification and approval grant supply chain participants access and enable them to carry out essential procedures, which primarily rely on the nature of the supply chain. Without a consensus-building procedure, supply chain participants are unable to alter the requirements for authorization and approval (Maurer, 2017).

The applications of smart contracts are observed in the procurement sector in addition to supply chains. When it comes to buying, two trading partners can use a smart contract to lawfully update the automated track of the goods that were purchased, sold, and delivered in real time. Beyond merely product delivery and governance issues, a smart contract has enormous potential for ongoing supply chain process improvement, design, and real-time implications (Saberi et al., 2019; Sivula et al., 2021).

5.11 Supply Chain Management Using Blockchain

A few of the key benefits that blockchain technology provides to improve supply chain system integration and coordination are its basic features of openness, confirmation, automation, and tokenization. Conventional SCM systems' primary flaw is their inadequate end-to-end transparency. Blockchain technology allows multiple supply chain participants to share current data about the place and state of an object. It is now possible to track any measurable situation, like the outside temperature of a product in the cold chain or the accessibility of technical equipment in a supply chain, thanks to sophisticated sensors and the widespread use of IoT. Improved information accuracy also facilitates the use of both reactive and proactive risk management techniques (Rizwan et al., 2022; Aslam et al., 2021; Dujak et al., 2019).

Furthermore, the Blockchain offers a centralized database with easily accessible and immutable records, enabling people to monitor assets straight from their source. The authenticity of provenance data ensures the integrity of assets, including both objects and technical equipment (Hasan et al., 2022). This could impose ethical sourcing requirements and enable the detection or avoidance of fake goods and other fraudulent activities.

Applications could involve finding an object's owner after a sale to fulfill warranty obligations. By ensuring that goods documentation, like the ones utilized in customs clearance procedures, is legitimate, it also lessens the amount of documentation involved in international trade. Smart contracts are used to combine automation with transparency and validation, resulting in a highly automated supply chain that operates according to predetermined rules. Data and related decisions or actions are dispersed throughout the supply chain, which speeds up and facilitates coordination (Kaur et al., 2022; Sudha et al., 2021).

To put it more clearly, should a machine malfunction, it may get in touch with the supplier to ask for a replacement part, request restoration, and notify stakeholders further down the line of any possible disruptions. The list of Blockchain's contributions to the SCM industry is displayed in Table 2 below.

Table 2. Contributions of Blockchain in Supply Chain Management. (Uddin et al., 2023)

Properties	Sub-Domain	Major Contributions
Consistency [72]	• Customer Assistance • Manufacturers' support • Longevity of shares • Accuracy of predictions	• Increasing information accuracy and reducing errors and mistakes • assisting manufacturing automation • improving the effectiveness of production processes • Increasing the effectiveness of supply chain operations • Increasing the precision of predictions
Neutrality [73]	• Design adaptability • Availability of purchases • reliability of the source • flexibility in production • reactivity of the delivery • Selling adaptability • Availability of returns • Adaptability of the supply chain	• Removing mediators as well as directly involving stakeholders • Promoting stakeholder collaboration and communication • Facilitating the sharing of information and resources among stakeholders • Minimizing transactional expenses and time • Improving production techniques • Enhancing operations • Reducing production duration • Reducing client response times • Reducing the duration of maintenance
Resilience [74]	• Providers' adaptability • Adaptability in the supply • Flexible production methods • Adaptability in delivery	• Avoiding intermediary firms along with directly involving constituents • Facilitating information and resource sharing among stakeholders • Facilitating interaction as well as collaboration among stakeholders • Promoting the development of innovative processes • Facilitating the decentralization of operations • Supporting quick decision-making • Maximizing collaboration • Increasing the industrial process's flexibility • Improving the ability to make personalized goods • Enhancing responsiveness to transformation and agility
Fiscal performance [75]	• Cost of design • Cost of manufacturing, • Cost of shipment, • Cost of return • Supply chain constraints	• Lowering hazards • Lowering risk-related expenses • Strengthening stakeholder trust • Minimizing transactional expenses • Lowering information tracking and verification expenses
Quality [76]	• Quality of goods or services • Performance of suppliers in terms of quality • Quality of production	• Promoting stakeholder information exchange • Facilitating access to information on products, suppliers, retailers, manufacturing, and supply chain operations • Enhancing process surveillance • Simplifying the diagnosis of faults • Allowing buyers to check the product quality • Confirming that products adhere to quality control standards • Ensuring that products are legally sourced and in compliance with the law • Enhancing quality assurance and surveillance

Table 3 provides a comparative analysis of the blockchain techniques, while Table 4 displays an analysis of supply chain systems that have adopted blockchain technology.

Table 3. Comparative analysis of blockchain techniques. (Uddin et al., 2023)

Blockchain Techniques	Privacy	Security	Consensus	Speed	Scalability	Transaction Cost	Incentive	Smart Contracts
Bitcoin	No	No	Computationally Intensive PoW	7 transactions per sec	No	High	Required cryptocurrency	No
Ethereum	Yes	Yes	PoW and PoS	15 transactions per sec	No	High	Required cryptocurrency	Solidity
Hyperledger	Yes	Yes	Multiple approaches	3000 transactions per sec	Yes	Low	It does not require cryptocurrency	Yes

Table 4. Analysis of Blockchain adopted supply chain systems. (Uddin et al., 2023)

Supply Chain Area	Technology Used	Framework Model	Contribution
Business application	IoT-integrated blockchain smart contracts	Conceptual framework	It enables effective resource and service sharing. It automated the workflow models of the time-consuming tasks.
SCM	Blockchain-based data storage	Conceptual framework	It helps to reduce the transaction cost and improves the process of executive commitments.
SCM	Blockchain-integrated IoT data storage	Conceptual framework	It assured the properties of data validity and traceability.
Manufacturing sectors	Blockchain model	Conceptual framework	It helps to improve the supply chain operations in the manufacturing industries.
SCM	Information management	Empirical model	Better adaptability and traceability in the supply chain.
Logistics-based business modeling	IoT-integrated Hyperledger technology	Use case model	It helps to improve the efficacy of inbound logistics with better traceability.
Supply chain risk management	Artificial Intelligence (AI) based blockchain technology	Conceptual framework	It supports enhancing the resilience of the supply chain system.
Supply chain in e-commerce industries	Distributed blockchain technology	Empirical model	It safeguards highly sensitive information by avoiding intermediaries.
Financial sector	Blockchain-integrated IoT framework	Conceptual framework	It helps to facilitate market establishment with ensured traceability.
Supply chain provenance	Hyperledger technology	Conceptual model	Data validity and accuracy.
Business application	Decentralized data storage and security	Conceptual model	It helps to improve the decision-making capability in the supply chain.

The initial wave of blockchain technology, commonly known as the Bitcoin blockchain, consists of network systems based on cryptocurrencies. The nodes in a Bitcoin network represent users; Every node possesses a duplicate of the identical ledger, to which fresh data blocks are progressively appended. A block may comprise different kinds of data, some of which are the sender, the recipient, and the transaction amount. A block is further identified by its hash or message digest. Every block contains extra information like a timestamp and a unique hash that is computed from the data in every block. Ethereum is a blockchain that is powered by cryptocurrencies, just like Bitcoin. Its foundation is a public network that can be leveraged to create a blockchain with controlled access.

Ethereum and Bitcoin both use the Proof-of-Work (PoW) protocol, which enables the development of decentralized applications on top of Ethereum through the implementation of smart contracts. It is among the Ethereum blockchain's most important characteristics. It has gained a lot of popularity for using smart contracts to create decentralized applications because it was the first blockchain platform to introduce the concept of smart contracts. one of the Hyperledger series' most advanced blockchain platforms. A fully permissioned blockchain network called Hyperledger Fabric was created for use with sensitive and confidential data applications. Because of its incredibly strong privacy and security features, hyper ledger technology supports granular permission, secret channels, and zero-knowledge proofs (Liang et al., 2022; Uddin et al., 2023).

5.12 The Effects of blockchain technology in the supply chain management

In order to negotiate better quantity discounts, Blockcain Technology applications can assist in tracking the purchasing activities of the organizations. Through precise demand forecasting and Supply Chain resource management, Blockchain Technology assists organizations in mitigating the risk associated with supply chains. Blockchain Technology is able to keep an eye on and verify the manufacturing parameters in the manufacturing domain.

Data-driven, Industry 4.0 technologies produce vast amounts of data that are needed to make wise decisions. The big data produced by industry 4.0 technologies can be utilized with Blockcain Technology. Better process documentation results from the integration of additive manufacturing with Blockcain Technology, which enhances the features of the product design. Through the standardization and distribution of the quality documentation processes throughout the Supply Chain, Blockcain Technology can increase the efficiency of the participants.

Wipro has created a Blockcain Technology application to detect and remove fake goods, offering a high degree of product transparency. Tracking vehicles and managing freight are two major ways that BT can help with logistics and transportation. Organizations are cognizant of the advantages that BT offers, but a full-fledged implementation in the SC is still a way off.

The value that Blockchain will bring to an organization should take precedence over the exaggerated claims made about its advantages when it comes to adoption decisions. In this study, we assess how BT adoption affects SSCP in the rapidly digitizing Indian automotive industry, which transforms the whole business model. According to recent studies, many automotive stakeholders and industries have used BT to accomplish scalability, auditability, and continuous surveillance in connected cars, autonomous vehicles, and cybersecurity. The automotive

industry's primary functional areas that can benefit from blockchain technology are manufacturing, logistics for supply chains, retailing, and leasing (Uddin et al., 2023).

In the subsequent section of Chapter 5, we will conduct an in-depth analysis of the outcomes of integrating blockchain technology into supply chain operations, encompassing its advantages, challenges, limitations, and accomplishments. Furthermore, we will undertake a comparative examination between conventional supply chains and those underpinned by blockchain technology.

Subsequently, we will explore the impact of blockchain implementation on achieving transparency, sustainability, and efficiency within the supply chain, while also delving into pertinent case studies. This section aims to provide a comprehensive understanding of the multifaceted implications of blockchain technology in reshaping the landscape of supply chain management, aligning with the objectives of this master's thesis.

5.13 Leveraging Blockchain Technology in Supply Chain Management: Addressing Market Imperatives and Consumer Demand

Growing customer demand for product origin information is a major driver behind businesses choosing blockchain for supply chain visibility. Customers can now share information more easily thanks to the internet, and blockchain technology may provide the sort of visibility that the system can verify. Customers may receive higher-quality services due to the quantity and caliber of visible data which this may provide, adding value. Customers "increasingly demand of an understanding of how, where, and when goods are sourced and processed," according to (Wang et al., 2019).

The goal of increasing visibility has prompted trials of blockchain technology in supply chains. Because "the 'classic' approach of monitoring and tracking is costly, unclear, and fails to meet the consumers' need for visible operations on the supply chain," Bext360, for instance, is utilizing technology to ensure the origin of their coffee harvest. Businesses also want confirmation that they can provide ethical products to their customers for reasons connected to human rights. Businesses and consumers are afraid of child labor and forced labor. Increased corporate social responsibility may help combat other types of business misconduct. The best way to address labor concerns like "modern slavery" is to provide customers with precise, in-depth information about the product's authenticity.

Provenance has tested blockchain technology in products like seafood and leather goods to meet customer requests for details, including Indonesian human rights issues. The company met customer demands for increased visibility while also promoting sustainable development by using cell phones and smart tags to gather data for a blockchain (Rogerson et al., 2020).

On the other hand, the additional revenue chances in Software as a Service (SaaS) caused the global supply chain market to soar to over $19 billion by 2021. There are many issues with supply chain management (SCM) that the supply chain business must deal with., despite its immense growth potential. A logistics network's various stages can be adversely affected by various factors, such as inadequate transparency and information sharing, or delays in data retrieval. Furthermore, the industry is having difficulty handling the lack of decent product identification and

traceability because of the centralized and separating systems in the current SCM. The data gathered from supply chains must be saved, combined, and retrieved with high efficiency and dependability if supply chain management is to continue its revolution in performance. An increasing number of individuals are using blockchain technology for supply chain management as a solution to the aforementioned issues. (Wu et al., 2019).

5.14 Blockchain opportunities in the supply chain

According to (Sivula et al., 2021) there are numerous applications of blockchain technology in supply chains and networks. Both new and improved business opportunities are presented. This study offers potential paths for blockchain technology development and logistical network businesses. Based on a multi-case study, Figure 7. shows several blockchain technology opportunities. Blockchain technology opens up the possibility of expanding customer value. Recoding supply chain data is possible thanks to the digital ledger system.

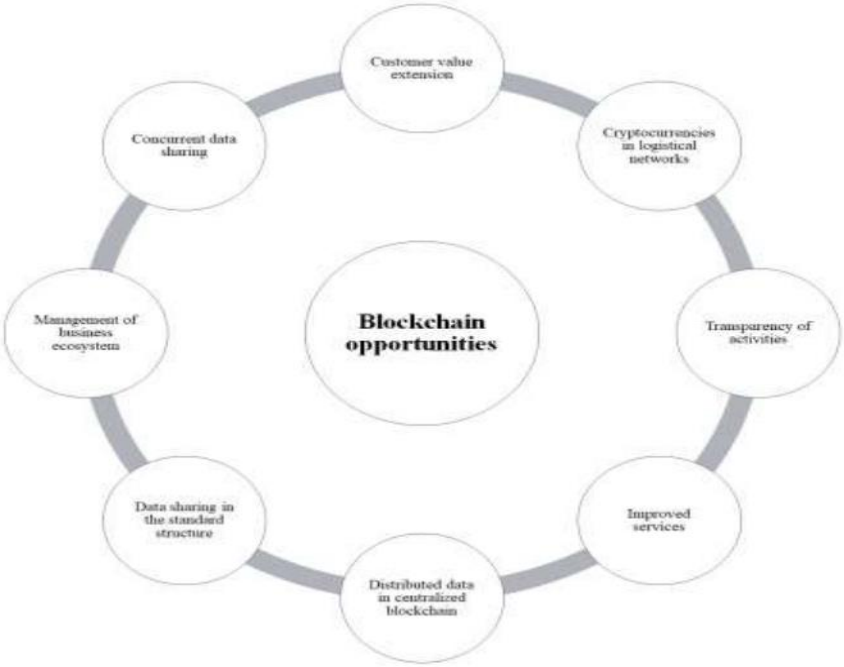

Figure 7. Opportunities of blockchain technology. (Sivula et al., 2021)

For the end user, this kind of system can offer useful services and information. Examples of these include tracking the construction process from start to finish, reporting the current status, and tracking the costs of the wood construction item in the supply chain. Furthermore, the same information can be modified and shared amongst various supply chain partners. Concerns about privacy should be high on the list of priorities, and everyone involved in blockchain should be aware of their respective roles. To add value, cryptocurrencies can be incorporated into logistical

networks. Cryptocurrencies such as Ethereum offer multiple methods for money transfers between various organizations.

The payment process does not require the involvement of a bank. For example, cryptocurrency can be used for instantaneous transactions following each stage of the supply chain. For example, this kind of process would benefit from international sales. For these kinds of activities, only a few unique cryptocurrencies could be used (e.g. supply chain cryptocurrency). Nevertheless, some study participants did not recognize the relationship between cryptocurrencies and their use when utilizing blockchain technology for logistical purposes. Transparency in operations is made possible by blockchain technology, which is crucial when multiple companies are involved in the supply chain.

Blockchain technology connects many organizations, including the customer, which offers a method for overseeing the whole logistic blockchain. It should be noted that blockchain transparency does not imply that all data contained within the blockchain is fully accessible to all participants. Transparency is important, but privacy should always come first. Many infrastructures frequently need maintenance, and as a result, these tasks are necessary for many organizations. Several organizations can offer the customer better services both during and after the construction process. Because blockchain data must be at a high level, only the customer's request should be able to access it.

Renovation projects are one application for this data. A single accessibility to the blockchain can be granted by the customer to multiple organizations to use the data in renovation projects. When numerous entities are involved in the construction process, the same sort of procedure can be modified. The buildings and infrastructures, for example, require a lot of data. Examples of this data include contracts, CAD models, reports, and plans. This type of information can be processed using immediate connections to external systems that are owned by various entities, but it cannot be directly added to the blockchain. This kind of blockchain implementation uses distributed data in a centralized manner.

As a result, this kind of blockchain serves as a concentrator for multiple systems and contains information about the location of the final data. The blockchain may be used to store transaction data, and since various points of view must be taken into consideration, blockchain development must be comprehensive in its approach to various logistical problems. In various systems, data can be represented in different formats. An important advantage of logistics networks is the standard format in which data can be distributed and shared. This opens up several possibilities in logistics, such as data systems and documents based on the Internet of Things. All the participants within the logistic network can then use the data that smart sensors can directly insert into the blockchain. Furthermore, the blockchain can be used to distribute additional documents and links.

However, when using the blockchain, all participants should adhere to the same procedures and share the same schema. Blockchain offers a fresh approach to overseeing the commercial ecosystem. Each party can participate in the network of logistics and, as a result, oversee their operations throughout the logistics procedures. Real-time access to the process's status and other relevant data allows the sender, receiver, transporting companies and other businesses to modify their operations in response to changes in the logistic network. Because of the information provided by the blockchain, the entire business environment will benefit. Concurrent data sharing is made possible by blockchain technology.

Transparency is increased because all organizations included in the logistics blockchain system have access to the same data. The blockchain also improves data fidelity, and machine learning algorithms can be used to analyze the data. The blockchain architecture also requires a high degree of accuracy to be maintained. Based on case studies, private blockchains would be most advantageous for various organizations. This directly relates to the privacy of data. Therefore, during development, one of the primary concerns should be privacy and security levels. To be certain about the main risks associated with using blockchain technology in supply chain networks, more testing and pilot projects are needed (Sivula et al., 2021).

5.15 Blockchain challenges in the supply chain

Even though the blockchain offers many prospects for use across numerous sectors, there are drawbacks as well. The difficulties with blockchain technology are outlined in Figure 8. based on this multi-case analysis. The lack of laws or regulations specifically pertaining to blockchains presents the first significant obstacle. Even though private organizations may own the blockchain, public organizations and the government should still impose some regulations. For example, these could be some fundamental details about the parties involved in blockchain and how it is being used.

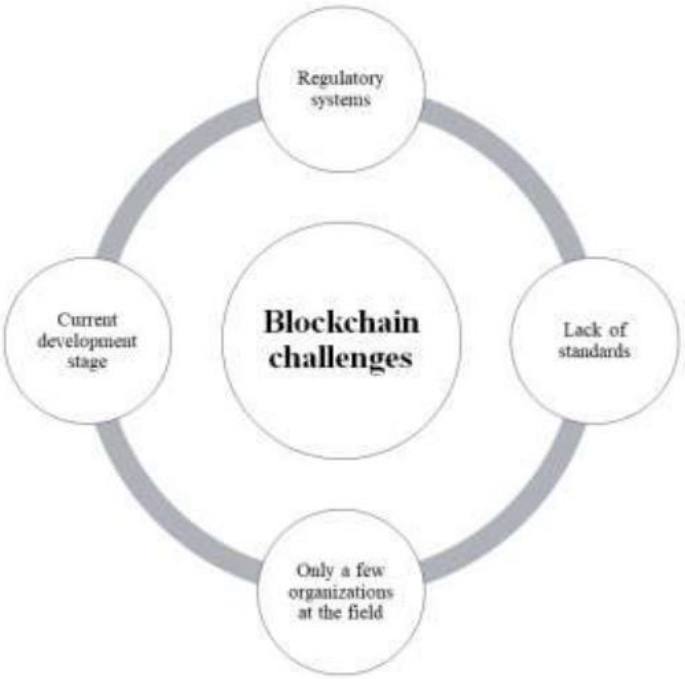

Figure 8. The challenges of blockchain technologies in logistics. (Sivula et al., 2021)

For instance, to maintain the accuracy of the information, the national government may use its systems to authenticate the business and guarantee its identity. If not, there may be security concerns about the companies' identities. An additional significant obstacle is the lack of a defined

standard for blockchain architecture. Since many systems are interoperable, one important standard benefits every player in the field. For logistical activities, a single blockchain schema must be chosen to offer suitable development opportunities for the industry.

The UBL schema is one schema standard that was applied in the case organization. It can be applied in a variety of ways to logistical blockchain activities. The third difficulty is that there aren't many companies in the industry working on blockchain development for logistics. More players participating could have long-term advantages for the advancement of blockchain technology in logistics. Therefore, additional testing and piloting are needed to improve the technology and model's efficacy and suitability for use in business ecosystems.

To increase the technology's appeal to various kinds of organizations, additional applications are essential. The current stage of development is the fourth challenge. Based on the interviews performed for this study, blockchain is currently being tested and piloted in the logistics industry, but it is still more in the idea stage than the production stage. Thus, it can be said that further study and advancement are needed to boost blockchain technology's efficacy in a variety of applications.

5.16 Utilizing Blockchain Technology in Supply Chain Management: An Academic Examination

All parties engaged in supply chain transactions can gain a great deal from blockchain technology and distributed ledgers, which also speed up procedures and facilitate more accurate, efficient, and secure data sharing. They also accelerate cash flows, lower overall costs, and simplify complex processes (Hofmann et al., 2018; Fanninget al., 2016). (Treiblmaier, 2018), however, notes that the application of Blockchain technology to supply chain financing facilitates faster operations, lowers overall program costs, lowers transaction fees, boosts speed and transparency, and allows businesses to use smart contracts to negotiate terms related to quality, delivery dates, and prices.

According to (Azzi et al., 2019), The system that moves goods or services from a supplier to a customer is called the supply chain, and it is made up of individuals, businesses, organizations, activities, data, and resources. As the integration of Blockchain has an effect on the structure of the supply chain, (Al-Amyan and Safhan, 2020) noted that a genuinely dependable, transparent, and safe system is created when Blockchain technology is applied to the supply chain utilizing the characteristics of the Blockchain.

Furthermore, (Rabie, 2020) discovered that the implementation of a blockchain-based accounting information system has a major influence on reducing the coronavirus's spread. It does this by standardizing data throughout the supply chain, providing timely, accurate, and reliable information, preventing accounting errors and adjustments, and providing accounting information as soon as an event occurs. Additionally, it monitors the performance of each party in the supply chain, increases transparency amongst all parties, shortens customer satisfaction times, lowers transaction costs, and boosts supply chain sales and profits. Blockchain technology is an open-source protocol which employs Bitcoin to pay for large-scale supply chain transparency.

Furthermore, (Mohd-Jamal et al., 2014) noted that there is a positive correlation between management accounting techniques and supply chain performance, meaning that management accounting approaches increase the efficacy of supply chain performance. Furthermore, according to (Khademi et al., 2019), supply chain performance has benefited from blockchain. According to (Fabian et al., 2018), traceability enhances the supply chain's quality and adds value through a variety of mechanisms throughout the framework of two distinct supply chain structures operating concurrently. This is because traceability can be used to track suppliers and increase buyers' ability to make cash flow more feasible.

Additionally, according to (van Hoek, 2019), Blockchain technology has increased the value of businesses provided they adopt a long-term perspective and realize that it will take time to fully grasp the potential of Blockchain technology, develop the necessary operational and strategic support, and turn it into apparent and sustainable sources of value. Furthermore, (Hald et al., 2019) discovered that the traceability feature of Blockchain technology, which stems from its capacity to deliver extremely stable data, presents an opportunity to leverage resources and efficiencies in the supply chain. According to (Hastig et al., 2020), supply chain tracking applications involving blockchain and trust are crucial.

Furthermore, (Ghode et al., 2020) show that, in the present competitive environment, implementing the idea of supply chains powered by Blockchain technology significantly affects product cost and increases market share. According to (Al-Sagheer, 2020), the application of blockchain technology to value chain analysis support, manufacturing supply chain monitoring, relationship and effort organization, activation of the cost goal method, and open records accounting as ways to control costs along the chain and strengthen its competitive advantages are all positively correlated.

According to (Chod et al., 2020), supply chain transparency can be obtained on a large scale at a cost through Blockchain technology, which is an open-source protocol utilizing Bitcoin. Furthermore, (Mohd-Jamal et al., 2014) noted that there is a positive correlation between management accounting techniques and supply chain performance, meaning that management accounting approaches increase the efficacy of supply chain performance. Furthermore, according to (Khademi et al., 2019), supply chain performance has benefited from blockchain.

5.17 Managerial Implications of using Blockchain in Supply chain

Managers of supply chains can monitor and assess their goods, services, and carriers by using blockchain technology, which aids in their decision-making. Blockchain technology reduces the risk of product fraud and streamlines payment systems for exchange. Additionally, supply chain networks can benefit from forecasting, optimization, and forward visibility thanks to blockchain technology. It is possible to integrate a number of supply chain processes using this technology, including manufacturing, shipping and delivery, fulfillment of orders, distribution, invoicing, and payment. Businesses benefit from this technological integration because it captures the entire value chain in which stakeholders have invested at any given point in the supply chain network.

By leveraging blockchain technology, supply chain managers can highlight at least five crucial product dimensions: the product's nature (what it is), quality (how it is), quantity (how much of it

there is), location (where it is), and ownership (who owns it at any given time). This eliminates the requirement for a reliable central agency to manage and operate the supply chain system. Customers can examine transactions using this system, from the purchase of raw materials to the final sale. As soon as any transactions take place on these various blockchain information dimensions, this transaction data is updated in ledgers with verifiable updates. Following this, customers can monitor a product's comprehensive details, which boosts their confidence in the features of the product.

Supply chain participants guarantee the legitimacy and access rights to goods in the value chain by implementing the entity "smart contract." This organization makes it possible to prevent any alteration or tampering with product information throughout the supply chain. A product can be legitimately transferred from one party in the supply chain to another using a digital signature. The development of blockchain gives managers the ability to build reliable supply networks and shared secure, decentralized ledgers. Additionally, peer-to-peer transactions between supply chain participants are supported by this technology, which lessens the need for intermediaries and middlemen and makes it easier to manage supply chain hazards and resilience within the network.

Blockchain has applications in sustainable supply chain management, tracking products and services, and governance. Concerns over developing sustainable solutions are becoming more and more prevalent these days. Businesses and their supply chains are under pressure to increase the sustainability of their supply chains and their goods from consumer associations, regulatory bodies, and community service providers (Zhu et al., 2017). Supply chain managers must take into account the impact of blockchain technology on sustainable supply chains in order to more precisely identify future supply chain implications from such business perspectives.

Apart from its security advantages, blockchain technology (BT) can offer numerous managerial advantages to routine business operations (Techlab, 2017; Takahashi, 2017). These advantages include: Lower transaction costs and times due to better-maintained blockchain platforms that do not require the involvement of third parties; Improved visibility throughout the supply chain due to increased transparency gained through publicly accessible open ledgers; Enhanced connectivity between trade partners via the incorporation of digital and physical worlds (Techlab, 2017; Takahashi, 2017), that includes shared visibility of transactions and data flows throughout the supply chain.

From an Engineering Management perspective, we figured out that Blockchain Technology can enable faster, Technologies such as electronic data interchange facilitate transparent transactions and the exchange of unchanging information across supply chain parties (EDI), extensible markup language (XML), and application programming interface (API) (IBM, 2017; Min, 2019).

5.18 Engineering Management: A Brief Review of Definition, Challenges and Trends

The multidisciplinary field of engineering management blends technical expertise with managerial abilities to effectively plan, organize, and carry out engineering projects. It entails applying management economics and quantitative decision-making technologies to project financing,

investment, and decision-making in engineering, construction, and real estate. By utilizing synergistic methodology and building machine-information environments, engineering management is also linked to the management and transformation of the new social reality (Htet et al., 2023; Galli, 2033; Korableva, 2020).

Stemming from the concepts and practices of management, including scientific management, it includes the methodical examination of available data to facilitate optimal decision-making. The role that engineering managers play in identifying technical obstacles, collaborating with stakeholders, and building a better future for technical organizations is another aspect of engineering management. Planning, organizing, and directing engineering activities are all part of the broad field of engineering management. It includes the process of conceiving, creating, and implementing new goods and services on time and within budget (Kiran, 2022; Essila, 2018).

The field is distinguished by its emphasis on practical, engineering-related abilities and is especially pertinent to large-scale projects. In addition, there is a rising need for training in this field as it is a fast developing field of study. The management of technological advances, quality, and transfer is now included in the broader definition of engineering management. The field has remained true to its engineering roots, placing a great focus on science and research, even in spite of its evolution. Enhancing engineering's effective contribution to wealth creation is the long-term objective of engineering management (Sahin et al., 2017; Sun et al., 1999; Omurtag, 2009).

Effective engineering management is more important than ever as globalization and technology improvements drive the complexity of engineering projects to rise. The landscape of engineering management has changed in recent years as a result of things like accelerated technological advancement, heightened competition, and changing customer expectations. Due to these developments, companies are placing a greater focus on innovation, adaptation, and teamwork. They are also adopting digital technologies, agile processes, and sustainable practices at an increasing rate. The field of engineering management is always changing as a result of globalization, industry demands, and technology breakthroughs.

The term "industry 4.0" describes the continuous digital transformation of various industries, which is being fueled by developments in big data analytics, cloud computing, artificial intelligence (AI), and the Internet of Things (IoT). By facilitating real-time gathering and analyzing of data, boosting operational efficiency, and facilitating better decision-making, Industry 4.0 is revolutionizing engineering management (Htet et al., 2023).

A variety of topics are covered by engineering management in supply chain management, such as the incorporation of lean manufacturing, RFID technologies, inventory control, and POM methodologies. The coordination of information, purchasing, and decision-making in the engineer-to-order and construction industries are also included. Gaining a competitive edge requires managing knowledge, and value engineering is a fundamental idea in enhancing supply chain performance. Additional important considerations are the move to a life cycle perspective and the investigation of worldwide sustainable supply chains (Dolgui et al., 2010; Cigolini et al., 2022; McGovern e al., 1999; Barbosa-Póvoa, 2009).

Supply chain management heavily relies on engineering management, especially in the engineer-to-order and construction sectors. In order to make wise decisions and boost output, it entails coordinating a number of stakeholders, including manufacturers and suppliers. This is accomplished by using contemporary methods for operations and production management, which

can improve the efficacy and efficiency of production systems. The main goals are to lower production costs, increase flexibility, and integrate all supply chain activities.

Furthermore, the idea of globally sustainable supply chains is becoming more and more popular, with a need to investigate sustainability and optimization challenges. A call for engineering management to include all of the responsibilities of engineers is made in relation to strategic planning. Lastly, the application of value engineering in supply chain management is highlighted as a means to improve performance and realize cost savings (Dolgui et al., 2010; Barbosa-Póvoa, 2009).

In supply chain management, engineering management is faced with a number of obstacles and viewpoints. The largest challenge is having to adjust to erratic global, regional, and national events, which calls for adaptability and preparedness to handle these changes. Construction companies must take precautions against management risks due to the influence of supply chain management on the caliber of their projects (Rostamkhani et al., 2022; Liao, 2019).

Improvements in the area of engineer-to-order (ETO) scenarios are also required. These include the conceptualization of engineering flows, supply chain integration, risk and uncertainty management, and the investigation of novel business models. Process System Engineering (PSE) can help with challenges related to the intricacy of supply chain systems and the various material and information flows. New perspectives from the industrial and academic domains are explored, and concepts for procurement excellence in engineer-to-order supply chains are developed. These are just a few examples of the perspectives in supply chain management (Cannas et al., 2021; Barbosa-Póvoa et al., 2018; Gosling et al., 2020).

There are many different engineering management perspectives and challenges in supply chain management. One important tool for handling the complexity of supply chain systems is process systems engineering. Design management faces many difficulties as a result of the trend toward using supply chains to coordinate design, development, and manufacturing. The largest obstacle that managers must overcome is the movement of materials from suppliers to the final consumer. Customized, complex products and market uncertainties are characteristics of Engineer to Order businesses that necessitate an integrated approach to marketing and procurement. New managerial challenges are brought about by the development of supply chain management and logistics. For a project to be successful, effective engineering management is essential, and organizations need to change quickly. Cross-functional integration is necessary for successful supply chain management, with marketing playing a key role (Barbosa-Póvoa et al., 2018; Htet et al., 2023; Roy et al., 1996; Mabert et al., 1998; Hicks et al., 2000).

5.19 Blockchain adoption in supply chain: Critical aspects, Challenges, Solutions, Obstacles and barriers

The initial phase of effectively employing blockchain technology for monitoring sustainable practices and overseeing products and supply chain procedures involves pinpointing the impediments and difficulties that require resolution. Partners in the supply chain must be aware of these challenges and prepare for them to adopt and apply blockchain technology.

Given the limitations, both internal and external, on an organization's ability to adopt new technology, the barriers are compiled and divided into four main categories: intra-organizational barriers, inter-organizational barriers, system-related barriers, and external barriers (Saberi et al., 2019). Blockchain technology is still in its infancy and faces a number of challenges related to organizational, technological, behavioural, and policy-related issues.

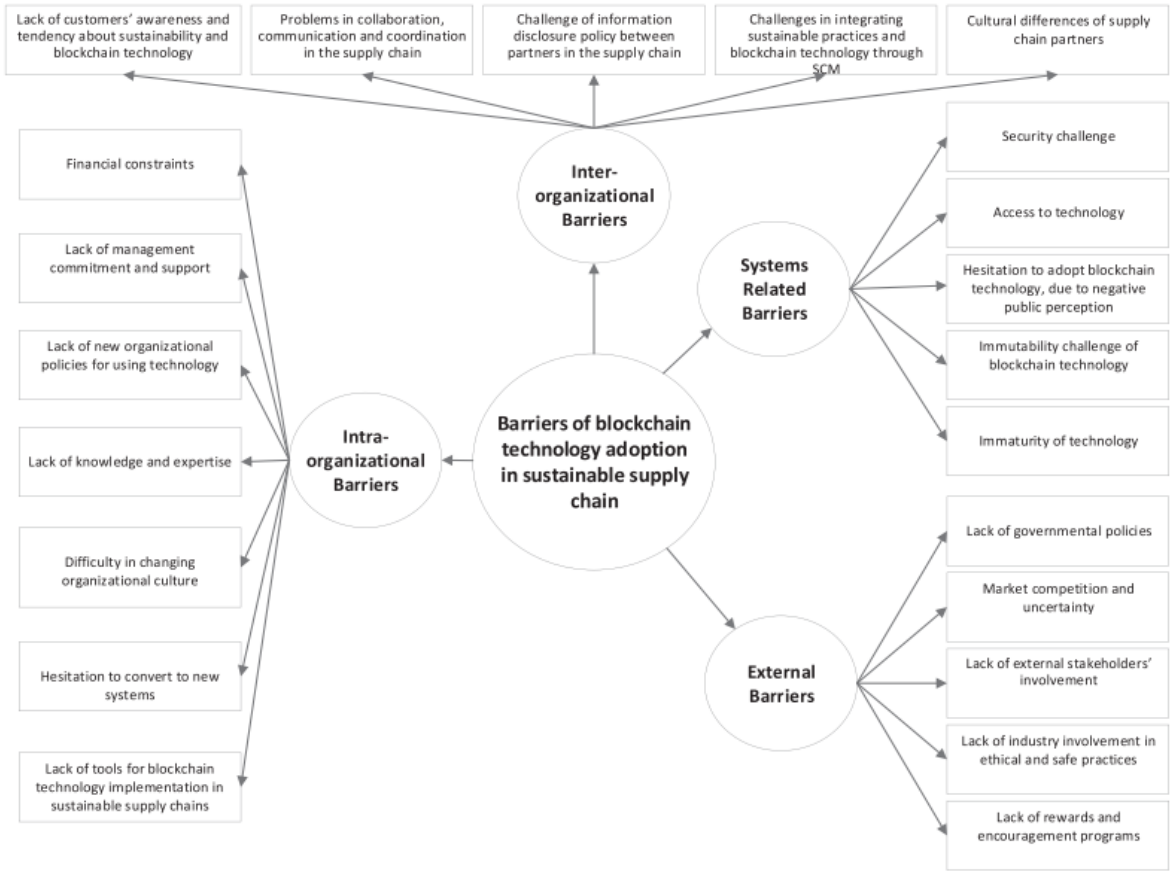

Figure 9. Barriers of blockchain technology adoption in sustainable supply chain. (Saberi et al., 2019)

Blockchain is a useful tool for solving supply chain problems with cooperation and trust. The "truth machine" deters businesses from engaging in any wrongdoing. Furthermore, a number of piloting programs or proofs-of-concept (POCs) have been created recently that use technology to analyze supply chains in order to provide traceability and transparency. Because Blockchain is a decentralized platform, data transparency is a feature by default. The public Blockchain's capacity to regulate data privacy or opacity in this situation is dubious, and supply chain participants possess private information that ought to remain private.

Supply chain projects add their own enhancement preferences to the existing Blockchain transparency feature, going far beyond what is offered. Blockchain integration with supply chain management is a relatively recent strategy. This novel strategy was implemented to achieve significant product traceability and sustainability for both businesses and individuals (Hellani et al., 2021).

There are various obstacles in the way of supply chain management's adoption of blockchain, including limited awareness, lack of strategic vision, cultural differences, and organizational readiness. Factors such as consumer awareness, empowerment, and regulatory changes are crucial for successful adoption. The lack of government regulations and global standards also hinders the adoption of blockchain.

The complexity of blockchain usage, arising from inter-organizational, intra-organizational, technical, and external processes, also poses barriers. Inter-organizational barriers include lack of information sharing rules, system-related barriers include new ICT tools, and external barriers include problems from external stakeholders and industries. The paucity of academic research on SCM and blockchain usage creates more opportunity for study (Buthelezi et al., 2021).

The proposed solutions to improve blockchain adoption in supply chain management involve increasing collaboration, communication, and coordination, creating government regulations, and establishing industry standards. Blockchain technologies are still in their infancy in agriculture, despite being well-developed in financial technology and cryptocurrency. Future discussions should focus on legislation and policies for integrating blockchain in fragile sectors. An SCM technology champion should help remove barriers to digital transformation and envision strategies for transforming processes.

The adoption of blockchain in Supply Chain Management (SCM) faces several challenges, including a lack of publications, lack of blockchain artifacts, and lack of interoperability within blockchain systems. Researchers are starting to see its promise in a number of fields despite its youth. The actual application is still in its infancy, and there is a scarcity of blockchain frameworks developed in SCM. Interoperability is crucial for data access across multiple blockchain systems, and businesses lack general awareness of blockchain technology, creating a barrier for adoption (Buthelezi et al., 2021).

While there is potential for a wide range of blockchain-based supply chain applications, these are typically industry, product or service, or governance specific. Solutions based on sustainability are gaining momentum. Businesses and their supply chains are under pressure from the government, customers, and the community to improve the products' and their supply chains' sustainability. These data compel us to examine the impact of blockchain technology on sustainable supply chains in order to more thoroughly determine the implications for supply chains in the future (Saberi et al., 2019).

5.19.1 Blockchain adopting challenges in supply chain

Despite the revolutionary nature of the technology itself, its adoption in applications is beset with numerous limitations and difficulties. Given this section's length, the technical and non-technical barriers to blockchain implementation in supply chains are covered in detail yet in a concise manner.

5.19.1.1 Non-technical challenges

Non-technical challenges in the supply chain industry comprise business executives' ignorance of blockchain technology, the perception of Blockchain as a fad, and a lack of industry-wide standards and practices. To be successful, key stakeholders must be convinced of the benefits of Blockchain, and market acceptability is a key challenge. Existing ERP systems often do not support Blockchain, necessitating outsourcing application development or in-house development.

Privacy leakage is a major concern in outsourcing, while in-house development requires significant investment and training for staff.

Additionally, the correctness of entered data is a crucial issue. Blockchain technology's immutability and transparency make it difficult for users to update or modify records. If a supply chain partner uses an unreliable system to record information, the addition of Blockchain technology can be detrimental rather than beneficial. The quality of data cannot be guaranteed by the immutability of Blockchain technology (Quiroz et al., 2019; Kim et al., 2018).

5.19.1.2 Technical challenges

Blockchain is much slower at retrieving and committing data than a traditional database. Additionally, a great deal more computational power is needed, and this raises serious concerns about the resources' scalability. Furthermore, all systems engaging with the Blockchain must be able to communicate with one another. The duration of the payment must be brief and adaptable enough to allow for the cashing in of any other currency, including FIAT money. In the subsections that follow, we concentrate on these two problems from the previous subsections.

5.19.1.2.1 Scalability

The capacity of a system to react and work even after the size of the input is increased in order to satisfy user demand is known as scalability. Although (Xie et al. 2019) categorized the scalability solutions into technologies pertaining to transaction volume, block interval duration, data transmission, and data storage, (Kim et al. 2018) classified the scalability methods into on-chain, off-chain, side-chain, child-chain, and inter-chain solutions to address the scalability issues. We offer a classification of scalability solutions into four categories: (i) distributed acyclic graphs based scalability (iv) consensus mechanism-based scalability (iii) off-chain scalability (iv) on-chain scalability. These categories of scalability solutions are shown in Figure 10.

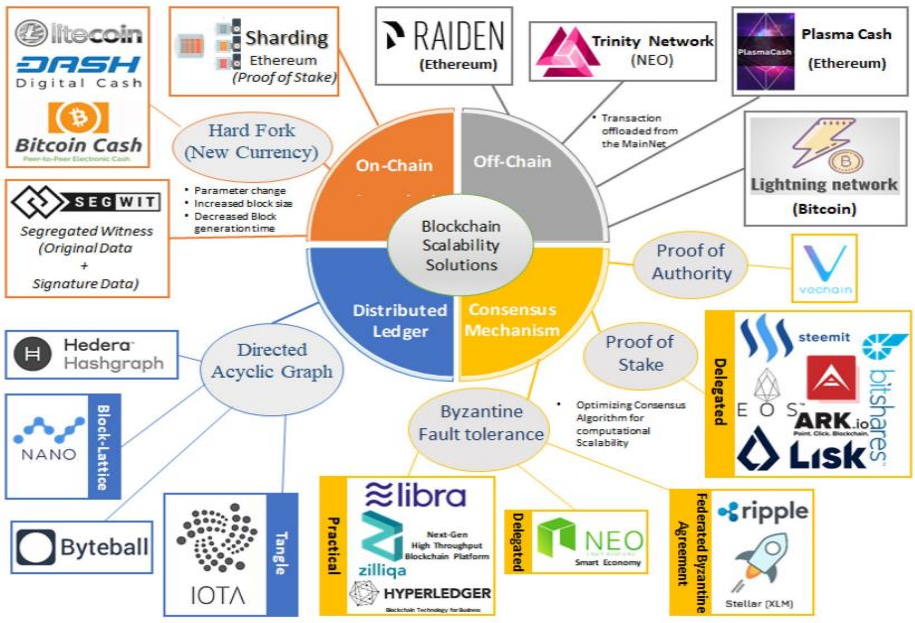

Figure 10. A taxonomy of Blockchain scalability solutions. (Jabbar et al., 2021)

5.19.1.2.1.1 On-chain solutions

Require a structural or fundamental alteration to Blockchain, and consequently a change to the protocol's guiding principles. When a community splits and factions that support or oppose the proposed update form, this is referred to as a hard fork, sometimes known as a contentious hard fork. The two main solutions are SEGWIT and Sharding. A few of the options for hard fork solutions are Bitcoin Cash, DASH, and Litecoin (Jabbar et al., 2021).

5.19.1.2.1.2 The off-chain approach

The off-chain approach is referred to as a second layer scalability solution because it makes use of secondary protocols that are built on top of the primary Blockchain. With this method, private transactions between the involved parties are carried out independently of the main Blockchain. It offers lower MainNet congestion, faster throughput, lower transaction costs, and more space savings. A few of the off-chain options that are out there are Lightning Network, RAIDEN, Trinity Network, and Plasma Cash (Lee et al., 2020; Bez et al., 2019).

5.19.1.2.1.3 In Consensus Mechanism based Scalability

Scalability concerns are addressed by optimizing the consensus algorithm's operation. Major solutions in this category are VeChain (Proof of Authority), ARK.io, LISK, bitshares, E.O.S., and steemit (Delegated Proof of Stake), Ripple and Stellar (Federated Byzantine Agreement), NEO (Delegated Byzantine Fault Tolerance), Libra, zilliqa, and Hyperledger (Xie et al. 2019).

5.19.1.2.1.4 Distributed Acyclic Graph-Based Scalability

Blockchain and Distributed Acyclic Graph-Based Scalability are not the same. This is yet another well-known application of distributed ledger technology. Transactions don't follow any specific process; instead, they function independently and asynchronously. The system keeps track of transactions using a topological ordering data structure. Blockchain technology has scalability problems that DAG distributed ledger technology does not. This category includes, among others, Hashgraph, IOTA, Byteball, and NANO solutions (Cao et al., 2020).

5.19.1.2.2 Interoperability

Although blockchain adoption is growing, a barrier to broader adoption is the isolation of blockchains in their respective "silos" brought about by a lack of interoperability standards. A hyper-connected world may be possible if cooperation and cross-chain interaction problems between public, private, and consortium Blockchains are resolved. Blockchain systems need to be able to interact with other systems, have common feature sets and capabilities, and use consensus models for transactions and contract functions.

The three categories of suggested Blockchain interoperability solutions are (i) Notary Schemes, (ii) SideChain Relays, and (iii) Hash Locking. In Notary Schemes, in order to facilitate operations, a trusted intermediary known as a notary witnesses and validates the state of the interacting Blockchains. Federated Pegged Sidechain by Liquid is a significant solution in this category. Relays are a common scheme for interoperability fixes. Among them are Cosmos, Polkadot, and ChainLink. Despite its limitations, hash locking is the most sensible method for achieving Blockchain interoperability. ARK Core Series and Interledger Protocol (ILP) are two of the main solutions that are currently available. (Jabbar et al., 2021).

5.20 The barriers of Blockchain technology adoption in supply chain

The first step in successfully implementing blockchain technology to track sustainable practices and manage products and supply chain processes is identifying the obstacles and challenges that need to be overcome. Partners in the supply chain must be aware of these challenges and prepare for them in order to adopt and apply blockchain technology. Considering an organization's internal and external constraints while introducing new technologies, the barriers are compiled and divided into four primary categories: intra-organizational barriers, inter-organizational barriers, system-related barriers, and external barriers.

5.20.1 Intra-organisational barriers

Barriers to successful implementation of supply chain practices in organisations include top management support, lack of long-term commitment, and the need for new organizational policies. Blockchain technology adoption requires costly investments in hardware and software, and may change organizational culture. Limited technical expertise and knowledge of blockchain technology can also hinder adoption. The Technology Acceptance Model (TAM) can predict the applicability of new information technology.

To achieve sustainable supply chains, organizations need to embed sustainability practices into their vision and mission, implement proactive plans, and have standard tools and methods. However, the early stages of blockchain technology and lack of business models and best practices can hinder successful implementation. Environmental regulations and customer demands can also hinder creativity in implementing sustainable practices. Despite these challenges, customers' awareness and willingness to contribute to sustainable development can improve creativity in implementing sustainable practices (Saberi et al., 2019).

5.20.2 Inter-organisational barriers

Supply chain management involves managing relationships among partners to create value for stakeholders. However, integrating information technology and sustainability practices can be challenging, especially when considering privacy policies. Blockchain technology can facilitate information sharing, but, some businesses can consider information to be an advantage over others, limiting its benefits. Different privacy policies may also pose challenges for data sharing.

Lack of solid rules for information sharing can affect collaboration among partners, and communication challenges can be worse in geographically dispersed regions with different cultures. Enhancing existing technologies is necessary to integrate sustainable practices with traditional supply chain procedures, designs, materials, and processes. RFID and the Internet of Things are potential solutions to address these issues, but they require additional facilities and devices to support sustainable practices.

5.20.3 System-related barriers

Blockchain technology is a crucial tool for supply chain management, but its implementation can be hindered by technology access limitations and storage issues. The technology is still in its early development stages and is considered immature in terms of scalability and handling large

transactions. The 'bloat' problem in Bitcoin refers to the storage conundrum that arises from managing large data for real-time use. Supply chain networks require even larger data requirements, including processes and practices.

Data manipulation and security are major concerns, with hacks and attacks being a significant issue. While some solutions have been proposed to mitigate these challenges, their effectiveness has not been evaluated. Blockchain technology is linked to digital currencies such as Bitcoin, which are known for their malicious activities, which slows its adoption. The immutability of information prevents falsification and adulteration of data, but humans still play a role in its implementation, with the risk of erroneous records remaining in the blockchain (Saberi et al., 2019).

5.20.4 External barriers

External stakeholders, industries, institutions, and governments in supply chain activities pose challenges to implementing sustainability and technological practices. Lack of appropriate policy and support for sustainable practices is a hurdle for achieving sustainability and advanced technological support mechanisms. Governmental regulations and laws regarding blockchain technology are unclear, and adverse policies about Bitcoin can affect broader usage. Blockchain technology should be promoted by governments, non-governmental organizations, businesses, communities, and trade associations in order to generate sustainable value.

Demand uncertainty for sustainable products and customers' behavior ambiguity may affect market competition and impede the integration of sustainability and blockchain technology. Organizations need to ensure their investments in green products, sustainable processes, and blockchain technology are compensated by their customers. Reviewing and clustering blockchain technology adoption obstacles will help understand new technology in supply chain networks and build sustainability aspects. Further research is needed to address wider contextual factors and advance the research agenda into blockchain technology adoption for supply chains (Saberi et al., 2019).

5.21 The Emergence of Blockchain-Enabled Supply Chain

Blockchain is starting to be used in a variety of supply chain applications, particularly in the manufacturing and financial sectors, to enhance efficiency in other areas and optimize processes. Its disruptive nature combined with the Internet of Things has made Blockchain one of the most exciting new technological trends in recent years. By combining these technologies, Companies are able to strengthen their relationships with their main stakeholders and attract new customers, particularly those that are present. For instance, it's estimated that companies in the food and pharmaceutical sectors are losing a significant amount of money as a result of various supply chain problems. These consist of product recalls, fraud, gray market, counterfeiting, and stolen goods.

Supply chain participants are moving toward greater traceability and transparency as a result of these factors. Blockchain looks promise, at least in terms of addressing the issues with traceability and trust, since it offers immutability, transparency, security, and fault tolerance. Businesses are already supporting the process with this technology in practice, and some have already proven positive results. A trial program for mango traceability from farm to fork has been effectively

started by Walmart and IBM. A joint project was started by Walmart, IBM, and Beijing Tsinghua University to develop a blockchain-based tracking and tracing model for the Chinese pork industry (Kamath, 2018).

In keeping with the IBM Food Trust initiative, IBM has partnered with Walmart to provide one of nine initiatives that offers food supply chains enabled by Blockchain technology. Suppliers of leafy green vegetables to Walmart have already been informed that, by September 2019, they must upload their data to the Blockchain. The most updated details about Wallmart's unparalleled supply chain openness may be found at. Examples of actual use cases for supply chains enabled by blockchain technology are provided in Table 5, with a focus on traceability. Everledger is another effective Blockchain-based method for tracking the origin of valuable assets.

Table 5. Real-world use cases of Blockchain-enabled supply chain (Jabbar et al., 2021)

Real-world use case	Company(s) involved	Purpose	Project status
Oil supply chain	Abu-Dhabi national oil company & IBM	Track oil from well to customers, automating transactions along with the way	Pilot program just completed; the Blockchain is still in its early stages
Diamond tracking	De Beers	Connect the diamond industry by establishing provenance, authenticity and traceability throughout the entire value chain	Successfully tracked 100 high-value diamonds along the value chain during the pilot of its industry Blockchain platform
Food safety	Walmart, JD.com, IBM, Tsinghua University	Improve food traceability by providing trusted information on the origin and state of food	A pilot program was completed in 2017, requiring suppliers of its domain and other leafy greens to upload their data to the Blockchain by September 2019
Logistics	Louis Dreyfus Co.	Secure Blockchain logistics solution	Completed the pilot program and has since gone on to implement Blockchain for traceability purpose
Fashion sector	Provenance, Martine Jarlgaard	Track every aspect of a garmentâĂŹs life through all the development phases	Currently conducts various case studies on further integration of Blockchain into the fashion industry
Wine Supplies	Origintrail and TagItSmart	Wine tracebility using Blockchain transparency capabilities	Conducted the first phase of their pilot program
Sea freight	Kuehne & Nagel and VeChain	Track parcels in real-time utilizing Blockchain in a variety of ways across multiple industries	Ongoing
Kenya coffee	Kahawa 1893 and Bext 360	Track production, establishing environmental goals and facilitating payments for women coffee producers in Kenya	Ongoing
Cassava producers	BanQu, Anheuser-Busch InBev	Provide more economic power to small cassava producers in Zambia	Piloted the first case study connecting 2000 Zambian cassava farmers to a Blockchain

The Blockchain has over two million diamonds uploaded for full provenance tracking from mine to final owner. At every stage, images or certifications are used to track this history. Carrefour, the biggest retailer in Europe, has integrated its system with Blockchain food traceability to provide customers information about the provenance of free-range chickens in Auvergne, France. Carrefour has extended the application of blockchain technology to other food products in this project, such as salmon, tomatoes, honey, eggs, and milk.

In an effort to enhance food supply chain traceability, British-Dutch Unilever and Swiss food giant Nestlé are also taking part in blockchain initiatives.

The Ethereum Blockchain's smart contract feature gives businesses the ability to manage massive volumes of transactions automatically and with complete confidence for both direct and indirect stakeholders. Despite the standard 30-day credit contract limit, supply chains may include sales remaining of up to 60 days in some Fortune 100 companies. Under these circumstances, managing unpaid bills is a difficult issue.

Automation of this procedure is now feasible because to programmable provisions in blockchain-powered smart contracts. The contract is set up to run automatically once a set of circumstances is met, which shortens the sales cycle. Cross-border goods movement is subject to strict

regulations; the clearance process is primarily handled manually and accounts for 15–50% of the total cost of shipping.

For instance, formal approvals from almost thirty organizations would be required in order to ship chilled goods from East Africa to Europe. Under the trade name TradeLense, Maersk and IBM have already started to transform their business model with the help of blockchain-powered smart contracts. Since 2017, their first pilot project which was constructed atop legacy systems has been running. In an effort to reduce shipping costs, this system supports a sizable network of shippers and their everyday activities and documentation. Australia's National Livestock Identification System is The World's Most Advanced System for tracking and identifying livestock. From birth to slaughter, the entire process of tracking livestock is monitored. Meat and Livestock Australia evaluated the application of Blockchain technology to facilitate provenance.

It examined how various supply chain players were using Blockchain to meet the provenance life cycle requirements. They ended by expressing a desire to put it into practice within their system. In a similar vein, the adoption of a Blockchain-based traceability system has advanced thanks to the integration of the Canadian Livestock Traceability System (CLTS) and the Beef Infoxchange System (BIXS). Canada requires the use of bar codes, plastic ear tags, or two electronic button ear tags in order to identify the original herd. The adoption of Blockchain-based solutions by other market participants has been spurred by these successful projects.

A team of innovation experts at Innovator's Guide conducted extensive and in-depth research on the possibilities of Blockchain in the supply chain business, and found that there are approximately 800 startups active in the space globally. Table 6 lists some of the most prosperous blockchain-enabled supply chain startups with a variety of themes, including traceability.

Table 6. List of some successful startups of Blockchain-enabled supply chain applications (Jabbar et al., 2021)

Name	Location	URL	Year	Business focus
DORÆ	UK	dorae.com	2014	Digitize & automate document processes
ShipChain	USA	shipchain.io	2017	End to end supply chain solution
Zego	USA	zegofoods.com	-	Provide traceability to food products & ingredients
Provenance	USA	provenance.org	2014	Empower brands to communicate the origin and impact of their products
Eximchain	USA	eximchain.com	2015	Reduce procurement cost & paperwork, and increase order fullfillment & transparency
OriginTrail	Hong Kong	origintrail.io	2013	Enabe a universal, collaborative & trusted data exchange for interconnected supply chains
PeerLedger	Canada	peerledger.com	2016	Protect human rights, reduce safety risks & improve environmental performance in their supply chains
Blockhead Technologies	Canada	blockheadtechnologies.com	2017	Increase product traceability & improve data governance for supply chain organisations
Zero1	Spain	zero1capital.com/	2017	Provide supply chain financing early in the production cycle
Cargocoin	UK	thecargocoin.com	2017	Link the physical worlds of trade, transport and logistics with Blockchain
Tradeline	Cyprus	tradeline.io	2017	Provide post-trade workflow automation platform
TangoTrade	USA	tangotrade.com	2018	Offer payment assurance to suppliers
Hijro	USA	hijro.com	2014	Connect financial & supply chain systems
Modum	Switzerland	modum.io	2016	Monitor, automate & optimize supply chain
Chronicled	USA	chronicled.com	2014	Help supply chain companies create standards & best practices
Sweetbridge	UK/USA	sweetbridge.com	2016	Keep all parties involved in a transaction in synchronisation
Skuchain	USA	skuchain.com	2014	Incentivize collaboration without compromising security or intellectual property
WAVE	USA	wavebl.com	2014	Securely store and exchange logistics documents
Blockverify	UK	blockverify.io	-	Anti-counterfeit measures of products, goods, merchandise & transactions
Fr8 Network	USA	fr8.network	2017	Improve operational efficiencies, compliance monitoring & payment settlement

5.22 DLT-based supply chains

Blockchain, and more broadly Distributed Ledger Technology (DLT), is an excellent option that allows for complete transparency of data records in order to overcome trust-related issues. It strengthens partner trust via a peer-to-peer decentralized platform based on cryptography that powers a supply chain. Since all records are kept within the ledger on every stakeholder system, employing the Blockchain platform in the supply chain removes the uncertainty that existed behind the collection of separate databases of conventional supply chain systems. Moreover, Blockchain prevents any records from being deleted or altered without leaving a trace. This is so that there is a clear understanding of the contents of the ledger as each partner has a copy of the same updated ledger (Hellani et al., 2021).

5.22.1 DLT-Based SUPPLY Chain Benefits

A strong contender to handle the aforementioned supply chain problems is blockchain. Data integrity and transparency are guaranteed during transmission and storage thanks to this technology. A distributed ledger technology (DLT) platform stores the history of data shared inside the network and operates independently of a dependable third party. Every network node has a duplicate copy of this safe database. A list of transactions and other particular data is contained in each of the chained blocks that make up a blockchain. It is a peer-to-peer (P2P) system that is fully decentralized and ensures trust between untrusted parties (Hellani et al., 2018).

Blockchains are characterized by their decentralized nature, shared ledger, immutability of records, tamper resistance, distributed trust, multiple-party consensus, and independent validation. Table 7 illustrates the four primary categories of blockchain technology: Anyone can access public blockchains (permissionless), like bitcoin. Consortial Blockchains are networks of pre-established organizations, private permissioned blockchains are restricted to one company, and public blockchains (permissioned) are accessible to anybody for data reading but not for data input (Rauchs et al., 2018).

Table 7. Blockchain types (Hellani et al., 2021)

			READ	Write	Commit	Example
Blockchain Ledger Types	Open	Public Permission	Open to anyone	Anyone	Anyone	Bitcoin, Ethereum
		Public permissionned	Open to anyone	Authorized participants	All or subset of authorized participants	Supply chain platforms viewable by public
	Closed	Consortium	Restricted to an authorized set of participants	Authorized participants	All or subset of authorized participants	Multiple banks or chain of restaurants operating a shared ledger
		Private permissioned	Fully private or restricted to a limited set of authorized nodes	Network operator only	Network operator only	Enterprise ledger shared among head office and branches

The supply chain is protected by the blockchain from numerous constraints and has improved functionality with regard to the following features:

Decentralization: A Blockchain-based supply chain's distributed ledger gives all parties involved the ability to see when information starts to deteriorate. As a result, Blockchain improves the validity of information while addressing problems with data corruption, hacking, and crashes in decentralized and independent systems. Furthermore, the suppliers can afford to implement this decentralized system (Tian, 2016; Bocek et al., 2017).

Automation: Smart contracts, which rely on predetermined rules and conditions to verify the performance of transactions among two or more parties, are the main foundation of blockchain applications. A self-executing program or script that is stored on the Blockchain ledger is called a smart contract. Once triggered, either by another smart contract or a participant node, it runs its code. Next, if the contractual terms are met, it transmits the content to every network node for verification and updates the ledgers appropriately. This automated procedure lessens the uncertainty associated with a supply chain's traditional contract, which does not require human intervention or reliable middlemen.

Trust: The primary outcome of distributed ledger technology, wherein participants possess a comprehensive understanding of the most up-to-date information, is transparency and trust.

Furthermore, the cryptography system makes privacy and anonymity possible. Therefore, in a decentralized supply chain network, there is no need to assess the reliability of the network's members. Because the Blockchain's underlying technology ensures that data records remain authentic even in the presence of fraudulent nodes, it is possible to assess trust amongst participants. Because all parties involved have the same data, which cannot be changed or removed, participants understand that the information is accurate. Resolving trust issues is therefore considered to be one of the implementation's primary justifications (Crosby et al., 2016; Casey et al., 2017).

5.22.2 Current Distributed Ledger Technology (DLT) Solutions in Supply Chain Management

The supply chain is necessary for every business. Consequently, the goal of integrating DLT with various stakeholders and legacy industries is to transform the global supply chain through the use of IoT, smart contracts, and decentralization features. These days, a lot of DLT-based projects aim to save money and time by implementing creative DLT platforms and gaining trust, transparency, and collaboration.

The UCL CBT Report's authors enumerated all 105 DLT-based IoT integration projects since 2008 and classified them into four categories without disclosing any of the projects' technical details. The majority of them are API interfaces that operate on Ethereum, the popular global Blockchain, but they lack clear technical citations and comprehensive publications. This section highlights data transparency and traceability while providing an overview of DLT-based supply chain projects and showcasing their technical components. The planned projects that use DLT in their supply chain are listed below:

(Dietrich et al., 2020) offers a conceptual model that makes advantage of a novel smart contract technique to address supply chain transparency. The three steps the writers take help them accomplish their objectives. The framework locates and includes each partner in the manufacturing process in the first step. Simplifying the actual procedure of alignment and product composition is the first step in a complex supply chain. This is not an easy task. This framework makes the assumption that every asset needs a special identification.

As a result, by creating the distinct identification numbers for each smart contract, a connection is made between each physical asset and the blockchain platform. These numbers are referred to as virtual identities, or hash'IDs, and they are all associated with distinct physical assets. Licenses, certificates, and other kinds of non-physical assets can also be referenced by hash IDs. In order to connect these numbers to the Blockchain, they are affixed to a bar-code format such as an RFID or QR code.

The supplier and the certifier two new roles in the framework are introduced in the proposal. The certifier's job is to certify suppliers so that the Hash'IDs can be generated. The manufacturer and other independent organizations may assume the Certifier's role, contingent upon the features of the supply chain. The second phase involves using the smart contract to logically attach each supply chain process to the Blockchain platform. In addition, the ultimate determination is made through a series of smart contracts that are documented on the unchangeable Blockchain ledger.

Ambrosus is an industrial project that tracks goods as they move through the marketplace. It is a supply chain powered by blockchain that is primarily concerned with safeguarding and managing food and medicine quality. The interplanetary file system (IPFS), a data storage solution, and a customized version of the Ethereum Blockchain make up the majority of this platform solution. Ambrosus creates its own independent, customized version of Ethereum in order to circumvent the high cost of processing transactions on the main Ethereum platform.

Furthermore, because Ethereum storage has a limited capacity, Ambrosus does not rely on it to store the supply chain data. Instead, in order to give the clients high throughput and scalability, it uses IPFS as the main storage for their large transactions. Ambrosus is equipped with highly sensitive sensors that enable it to identify and evaluate specific food and medication-related cases. As hash cryptography is the foundation of Ambrosus' transactional processes, they leverage the Merkle tree to their advantage.

This tree algorithm makes it easy for users to locate the data and remove incorrect inputs. There are two types of smart contracts introduced: the measurement smart contract stores the attributes collected throughout the supply chain to note variations in composition quality, the root hash of the Merkle tree, and a list of devices certified by Ambrosus. The requirement smart contract outlines quality standards that are directly compared to the items inside the measurements smart contract. To help users gain more visibility and expedite the tracking process, the Merkle tree data are periodically uploaded to the top Ethereum network. Ambrosus tags products with Internet of Things (IoT) hardware and sensors, enabling supply chain tracking and guaranteeing transparency and total data integrity.

Blockchain and off-chain networks are combined to create OriginTrail, a supply chain solution. It puts the off-chain network into practice on DLT-based nodes in a novel kind of decentralized setting. The Blockchain platform communicates with the non-DLT network while operating on various nodes. The OriginTrail Decentralized Network (ODN), an off-chain network, consists of

network and data layers. As a result, the platform, non-decentralized ODN, and stakeholder applications make up the architecture.

OriginTrail demonstrates confidential information without disclosing it thanks to Zero-Knowledge encryption. Additionally, the smart contract interacts with various off-chain nodes to ensure that a predetermined set of conditions are carried out. Utilizing this platform will allow for the storage of the data fingerprint, protection of record integrity and transparency, and provision of an unchangeable supply chain system.

Modum is a monitoring solutions supply chain that manages the distribution of large quantities of delicate goods, particularly pharmaceuticals. It is made up of the Ethereum network, the modum temperature logger sensor, and the API applications. There are two phases in a modum architecture: front-end and back-end. The Ethereum network, smart contracts, and a particular server that is directly connected to external users make up the back-end. The front-end consists of mobile apps and sensors that are connected via REST API and JSON to the HTTPS server in the back-end.

The primary added value for monitoring the environmental conditions of the shipments is the logger, also known as the SensorTag. In specifics, every shipment has a unique QR code called "track and trace," and every logger has a unique MAC address that is represented in the code. Using the user's mobile applications, scan both QR codes and send the results to the server. The server broadcasts the smart contract and stores the smart contract ID on the sensor after receiving the combination of QR codes. Through Bluetooth low energy (BLE), the client scans the "track and trace" code to obtain the temperature readings from the sensor.

For verification, the smart contract receives the data and reports back to the client's mobile device. Every time ownership changes when utilizing the smart contract, the authenticity of the data is verified. The evaluation's findings are then permanently saved as evidence of the entity. The Modum technique effectively addresses data transparency, and the product content does not need to be physically verified.

Vechain is a supply chain solution made up of the blockchain-based vechainthor platform and the vechain supply chain projects. Based on the Ethereum codebase, Vechainthor is a forked and improved version of Blockchain. The improvements take the transaction format in a number of different directions. Four fields are included in the new transaction format: independent ID, DependsOn, Blockref, and Expiration. As a result, the application handles a single transaction as opposed to a collection of transactions. Blockref gives further details about the previous, present, and upcoming blocks. Moreover, it offers details on the time at which the transaction was created. For financial reasons, for instance, this will be useful in the event that acceptance is delayed.

To prevent stacking for an extended period of time, an expiration is added to the transaction. Multi-task transactions: to handle intricate business payments, a transaction is made up of numerous smaller transactions. Vechain enables the tagging of items with a globally readable identity by integrating blockchain technology with Near-Field Communication (NFC), RFID, QR codes, and bar codes. The integration of novel transaction fields with Internet of Things technology facilitates precise tracking of an item's origin and deters counterfeiting because Blockchain records are non-duplicable or interchangeable.

Developed for verification purposes, Devery is an open-source protocol built on the Ethereum network that allows retailers to give their products unique signatures. Throughout the application

queries, these signatures which are kept on Ethereum are used to authenticate a product. Three data structures make up the Devery protocol, and they communicate with Ethereum via smart contracts called DeveryRegistery.sol and DeveryTrust.sol. The basis of the data structure is the registration of a good or service's public key with an application's unique identity. Each product's unique identifier is determined by the hash of the product information, which enables a lookup using a check method.

For payments and charges, Devery employs the Entry Verification Engine (EVE) token. Customers are not allowed to deal with EVE or gas tokens directly; instead, they have to reimburse the application host via Bokky's Token Teleportation Service (BTTS) for the good or service's verification service. Through the use of this protocol, supply chain verification is made possible across Blockchain smart contracts without requiring direct communication with the decentralized environment. By making reference to the standard Blockchain features, this protocol takes the transparency over applications.

A blockchain platform called Waltonchain was created to monitor RFID-based transactions involving numerous supply chain partners. It consists of numerous sub-chains that are mined and connected to the parent chain, which is a central network known as the parent chain. After being formed and registered in the parent chain, a sub-chain functions independently. Every sub-chain has its own ledger, and the parent chain ledger only holds information pertaining to specifics about each sub-chain.

A sub-chain can be formed at any moment and linked to the parent chain. The parent chain does not store the data from the various sub-chains since it operates separately from them. The Walton chain, which creates and manages the underlying logic platform, is built on the smart contract. Moreover, it creates an RFID integrated circuit tag that is appropriate for Blockchain uses. Supply chain sustainability and transparency are monitored using the standard Blockchain Ethereum platform and IoT innovations that facilitate the gathering of accurate data.

Shipchain is a completely integrated supply chain tracking system that allows shipments to be tracked from the point of manufacture to the doorstep of the final recipient. It makes use of side-chain and smart contract technologies and is based on the Ethereum Blockchain. Although records are stored on the Ethereum network, businesses can save money by storing and validating their own data on the side chains. Because of this, data is entirely decentralized and available in both the main Ethereum ledger and the side chain, neither of which makes use of a mediator. Furthermore, Shipchain offers a web platform that bypasses the conventional brokerage model and connects shippers directly with carriers.

Despite operating on the Ethereum network, smart contracts can be replicated and utilized by side chains for cost savings on Ethereum forks (ShipChain protocol). Consequently, every shipment is assigned a unique smart contract that increases shippers' visibility throughout their supply chain, enables carriers to communicate promptly, cutting down on delays and misunderstandings, and accomplishes the necessary level of overall transparency.

CoC stands for "Chain on Blockchain," a hybrid blockchain-based supply chain management platform designed to primarily address the problem of multiple entities' lack of trust. Generally speaking, certain nodes are encouraged to create and validate blocks in an authorized network. CoC organizes the underlying distributed ledger using a hybrid model that makes a distinction between record submission and block-building. Whereas building blocks are accessible to the general public through designated helpers, submitted records are restricted to users, third-party

users, and supporting entities exclusively. CoC developed a method known as "Two-Step Block Construction" to construct a distributed ledger on their hybrid platform.

Users create reservation blocks in step 1, and data blocks are generated in step 2. A user requests to reserve predictive blocks in step 1. In addition to other necessary details, the request contains the requester's information, the amount the user wishes to pay for the block, the helper's name and creation date. To reserve the block, the helpers must agree on something. In step 2, the user sends data to the ledger using the block or blocks they have reserved. Since assistance already validated the reserved block at the time of reservation, there is no proof-of-work computation effort required in this step.

The overall performance latency is not decreased by the two-step block reservation. As long as a user has enough reservations, it offers a way to change the latency. A new supply chain record can be added with very little delay. To put it succinctly, CoC suggests a new DLT hybrid mechanism that solely depends on embedded Blockchain features for transparency.

Tael (WaBI) is a decentralized application that enables the use of RFID labels with anti-copy features to establish a safe connection between digital and physical assets. The user installs it on their phone independently so they can use a mobile app to authenticate their product. Through the scanning process, which serves as a mining representation, the user is rewarded for each scan by completing a proof-of-purchase. A specified point of origin along the supply chain is where the "Walimai label," which is applied, is supported by the Walimai organization, which is referred to as Wabi.

WaBI tokens are used by the registered products under the "Walimai system." The Walimai labeling method offers transparency by securely and uniquely attaching the label to the product for the duration of its journey to the customer. When physical products are associated with a distinct encrypted code, customers can use mobile applications to scan that code and compare the digital and physical states of the product.

Aqua-Chain is a blockchain-based traceable water supply chain management system that can be deployed on Ethereum or hyperledger blockchains. Since IoT devices gather data along the supply chain and store it in the Blockchain ledger, data transparency is ensured. As a result, Aqua-chain software has been modified to fully trace their customers using the traditional "from-supplier-to-buyer" model. It has a tiered architecture that uses IoT and Blockchain to provide traceability. CRM and ERP are examples of traditional systems that can be integrated with Aqua-chain.

Applications that use REST APIs and are easily integrated with other software make up the front-end layer. The controller is the name of the middle layer. It is in charge of converting the low-level Blockchain call from the high-level function call and vice versa. Integrating IoT and DLT technologies with Aqua-Chain makes it possible to create transparent, fault-tolerant, auditable, and immutable records that are suitable for the water traceability system.

To combat food fraud and unreliable supply chains, TE-FOOD is an ecosystem that fairly integrates the farmer, producer, transporter, and consumer. This allows for successful farm-to-table food traceability. TE-FOOD presents the Blockchain protocol, RFID identification tools, plastic security seals, smart contracts, and a utility token called TFD. There are two sorts of blockchain involved in this process: a private blockchain that stores transactional data and a public Ethereum that is used for payments using TFD tokens.

Thus, supply chain enterprises need to have two types of wallets: a transaction wallet on the private network that TE-FOOD can access, and a wallet on the Ethereum network that can be accessed directly or through the TE-FOOD mobile app. The private Blockchains of the suppliers and customers are mediated by the public blockchain. For the purpose of tracking its product from various suppliers, the customer purchases traceability services via the public Blockchain. Then, TE-FOOD deposits the transactions it has purchased into the wallets of its suppliers. This project's contribution can be understood as "traceability as a service," in which suppliers must invest in order to achieve transparency.

Based on the Ethereum network, CargoCoin is a decentralized supply chain platform that seeks to connect goods traders to a single platform that houses all kinds of transport cargoes. To accomplish this, the services platform and smart contract technology are both used inside the platform. The platform gives the parties participating in the supply chain procedure access to an array of avenues for communication that they can use to send, receive, reject, approve, or sign documents. CargoCoin offers time and cost savings to EcoSystem participants by introducing smart utilities, which are represented by smart contracts and payments. Using the same decentralized platform, the participants' shipper, carrier, and consignee interact and establish terms and conditions.

Cargox is a decentralized global transportation solution built on the Ethereum Blockchain. It deals with the bill of lading paperwork and stays away from the logistical trading in the supply chain. Users collaborate via the dApp's API to design their intelligent bill of lading. They can choose between two methods: they can use the USD/CXO conversion mechanism or directly consume cargo token "CXO". Participants in dApps, which are based on public Ethereum and have smart contracts enabled, can take advantage of the DLT transparency feature. As a result, everyone associated with the transportation process importers, exporters, carriers, and others can manage shipments using their mobile devices.

A complete dApp called Cargox is released, enabling the carrier to start the smart bill from the beginning. After the exporter pays the shipping charges, the carrier sends the bill to their address; once the importer pays the goods price, the carrier transfers ownership of the bill to them. At the destination port, the importer asserts ownership of the goods by utilizing the smart contract technology integrated into the dApp. With the Cargox dApp, users can quickly generate intelligent bills. In addition, these documents are only readable by the parties involved, ensuring transparency in international trade.

ProductChain is a collaborative blockchain that was developed to improve food supply chain (FSC) traceability while accounting for transaction rates that can be completed in less than a second. Its primary method for enhancing scalability and guaranteeing consumer data availability is a three-tiered sharding architecture. Additionally, it presents the Access Control List (ACL), which allows consortium members to jointly manage read and write access while limiting access to rival partners. Not only does it outperform scalability, but it also adds transaction terms to store various kinds of data and interactions that cover every FSC process.

The final product can be connected to several raw ingredients that are pertinent to a wide variety of SCs using the transaction vocabulary. Productchain enhancements include a consortium-governed access control that ensures no participant controls the Blockchain and data transparency that allows a user to quickly track data back to specific key ingredients.

FarmaTrust offers a reliable cloud-based platform for tracking medications via a supply chain that connects digital devices to medications traveling through real-world locations. To improve scalability, it is built on the Ethereum Blockchain and uses the POA consensus algorithm. The global community, comprising suppliers, logistics and shipping firms, wholesalers, distributors, pharmacies, and hospitals, shares the FarmaTrust platform known as "Zoi." This international network makes use of the FamraTrust platform to guarantee data transparency to verify the authenticity of medications and related medical supplies. The customer can utilize the FarmaTrust mobile application to use a QR code scanner to confirm the product's authenticity as a last step toward total transparency.

A supply chain platform called Bext360 is used to improve food commodities globally and offer complete transparency from farmer to table. It's a software as a service (SaaS) that combines sustainability metrics with blockchain technology to give a traceable fingerprint from producers to customers. Retailers and wholesalers can integrate the technology into their websites, point-of-sale systems, or supply chain management tools thanks to its RESTful API. The supply chain's overall transparency is improved and food products can be tracked independently by all stakeholders thanks to the SaaS platform.

Blockverify is a blockchain-based anti-counterfeit solution designed for luxury supply chain products. Every product has a special tag that allows Blockverify to track it along the supply chain. The customer sets the transparency level. Blockverify is made up of a public Blockchain and Bitcoin that is used to progressively store both private and public data in separate ledgers.

BlockGrain is an agricultural supply chain which enables companies, brokers, and farmers to monitor the grain's progress from harvest to the end user. It is a decentralized platform that runs on the Ethereum Blockchain using the agricultural supply chain. Three layers make up its structure: applications, private blockchain, and public blockchain. Buyers utilize the private Blockchain to cut down on transaction costs and waiting times associated with the public Blockchain, while the core data, smart contracts, and transaction Agri tokens are kept on the public Blockchain. via the BlockGrain Platform (Applications Layer), both Blockchains are managed. BlockGrain completely automates the delivery process. At every stage, information is gathered and validated in conjunction with the distribution of goods. BlockGrain enhances transparency and visibility through this process.

ZERO defects is a platform that specializes in producing digital twins using a cutting-edge framework for traceability, identifying and addressing flaws at an early stage of production. It's an ISO-certified company Pickert and the IOTA Foundation-managed platform based on data acyclic graphs (DAGs). DAG is a different kind of blockchain DLT technology. With large incoming data loads, it adapts well and has low computation and transaction costs. The IOTA platform, being a decentralized application, enhances Zero defects by providing complete transparency and visibility for its board's unchangeable records. Every item has its individual serial number, which is stored and accessible immutably in the IOTA Tangle and uniquely identifies it with zero defects.

Based on a hybrid Blockchain system, Everledger is a Blockchain platform that specializes in preserving the integrity of valuable goods, like diamonds. It focuses on the immutability of the diamond history of transactions rather than the scalability of the system by using Ethereum as a blockchain that is public and Hyperledger that is private. Everledger creates a digital twin of every product by fusing nanotechnology, artificial intelligence (AI), and the Internet of Things. This method creates a permanent, secure digital record of the origin, attributes, and ownership of an

asset. With the help of this combination of technologies, customer supply chains are made more transparent, allowing for traceability on a private, secure, and unchangeable platform.

Chronicled is an industrial supply chain initiative that integrates the Mediledger network to increase automation and trust among businesses. The most transparent bridge among trading partners is the MediLedger Network, which combines a decentralized Blockchain network with a secure peer-to-peer messaging network. The physical goods are tracked and connected to the blockchain through "identity inlays and tamper-evident cryptographic seals" utilizing smart tags and the Chronicled App. A smart tag is a cryptographically secured chip that links to a private key and contains information about the physical good. This ensures additional data transparency for all parties involved.

Because of its speed and scale, NextPakk is a delivery service that uses Stellar's Blockchain to address last-mile problems. When the package arrives, customers can schedule delivery to arrive at their homes within an hour. Moreover, NextPakk tracks packages using Blockchain technology to safeguard customer privacy and guarantee on-time delivery. This increases the delivered goods' transparency by enabling customers to track their packages online instantly. Nextpakk leverages blockchain technology to streamline the last mile delivery process, enabling customers to track drivers and receive fully transparent information regarding the precise time of package arrival.

Fr8 is a supply chain network that uses blockchain technology at its core to modernize logistics and offer the industry a better overall solution. Its foundation is the coupling of RFIDs, shipment tracking IDs, and other documentation to establish significant connections between various datapoints. There are five layers in the Fr8 protocol. The shipment's data and metadata are located in the transport document layer. Permissions and data integrity are managed by the permission & ID Layer. Data is exchanged between the service layer and the document layer via the interface layer. Applications and the Fr8 Protocol are connected through the service layer. To display the data, the application layer collaborates with the interface and services layers. Fr8 mainly relies on the Blockchain idea as a single source of truth for shipment information to guarantee transparency. There will be unmatched visibility into shipments and the data they are associated with for all parties involved.

Moreover, maintaining solid connections with trading partners and streamlining supply chain processes are dependent on collaboration among production stakeholders. Disparate communications, however, as well as different levels of trading abilities and business processes, present difficulties. Data sharing between suppliers and subsuppliers in an open setting is necessary for a collaborative supply chain. The transparency of traditional methods, such as one step up, and one step down, is limited because they require suppliers to share information. IoT technologies and decentralized blockchain can help address these issues.

Blockchain is integrated with a number of solutions aimed at improving the modern supply chain, giving the system more traceability, transparency, and trust. Product traceability and data transparency are frequently improved by IoT devices and smart contracts. Using technologies like QR codes, smart tags, RFID tags, NEC, and mobile applications, IoT technology is used to track objects. Blockchain-programmed smart contracts guarantee the transparency of off-chain networks that are not a component of the blockchain. Additionally, methods like the Merkle tree algorithm, zero-knowledge proof, and modifying the Blockchain transaction format can improve traceability and transparency.

Supply chain DLT integration enhances data transparency and offers end-to-end traceability. Improved tracking techniques, like the Merkle tree algorithm, are used by projects such as Vechain and Ambrosus to improve tracing capabilities and increase transparency. By adding new fields to each transaction, such as ID, DependsOn, Blockref, and Expiration, Vechain is enhancing the fundamentals of blockchain technology. These parameters improve data transparency and achieve perfect traceability, and they can be utilized with any DLT platform without interfering with its functionality (Hellani et al., 2021).

5.23 Blockchain based supply chains

Blockchain technology has the potential to revolutionize supply chain operations, design, organization, and general management. Smart contractual relationships for a trustless environment and blockchain's ability to ensure information authenticity, traceability, and reliability all point to a significant overhaul of supply chains and supply chain management. While bitcoin and other financial blockchain applications may be public, blockchain-based supply chain networks may require a closed, private, permissioned blockchain with many, limited players. However, there might still be room for a more visible pair of partnerships. Determining the privacy level is one of the first choices (Saberi et al., 2019). An overview of one traditional supply chain's conversion to a blockchain-based supply chain is depicted in Figure 6. Supply chain transformation.

There are additional influences on the product and material flows in the supply chain. Every product might have a presence on a digital blockchain, granting direct access to product profiles to all relevant parties. Access to a product may be restricted by security measures so that only those holding the proper digital keys can use it. It is feasible to compile a range of data, such as the product's type, status, and the standards that must be followed for it (Tian, 2017).

According to (Abeyratne et al., 2016), an information tag affixed to a product serves as an identifier connecting tangible goods to their digital persona on the blockchain. One interesting feature of flow and structure management is the way a product is "owned" or transmitted by a particular player. Actors getting authorization to add new details to a product's profile or start a trade with another party will probably be a major rule, requiring consensus and smart contract agreements. In order to authenticate the exchange, both parties may sign a digital contract or fulfill a smart contract requirement before a product is transferred (or sold) to another actor.

When all parties have completed their contractual duties and procedures, transaction data are added to the blockchain ledger. When a modification is made, the system would automatically update the data transaction records (Abeyratne et al., 2016). At least five fundamental item dimensions that the blockchain technology may emphasize and specify are the essence of the product (what it is), its level of quality (how it is), the amount of it (how much of it there is), its place of origin (where it is), and its owner (who owns it at any one time).

The ongoing chain of custody and transactions from the raw ingredients to the final sale are now visible to customers, all thanks to the blockchain, which also eliminates the need for a reliable central organization to run and maintain this system. As transactions take place across these various blockchain information dimensions, this data is verified and entered into ledgers. With automated governance requirements, the transparency and dependability of blockchain

technology is intended to more efficiently facilitate the flow of information and materials through the supply chain. This change could lead to a more general transition from an information-based, customized economy to one based on industrial durable, commodity products. Production will be less reliant on the material's characteristics and more on information, communication, and knowledge (Pazaitis et al., 2017).

Customers' ability to follow product details, for instance, would boost their confidence in the features of the products. Blockchain affects financial transactions between various network participants as well as product management and supply chain processes. The disintermediation of financial middlemen, such as payment networks, stock exchanges, and services that transfer money, is a significant potential benefit of the blockchain supply chain.

Trading procedures between partners will become more effective as a result. Reverse factoring and dynamic discounting are two examples of supply chain finance tools and strategies that can reduce inefficiencies in financial flows and save networks millions of dollars. With the help of smart contracts, financial arrangements can be organized to guarantee that projects have enough funding and that everyone gets paid on time. In a timely and secure manner, they offer a link for transactions between various currencies or combine them from various sources in a global supply chain (Saberi et al.,2019).

Transaction settlement in traditional supply chains is slowed down and bottlenecked by the centralized, trust-based database systems. Supply chain disputes are caused by a lack of transparency and a vulnerability to fraud, corruption, and/or other wrongdoings. These risks and uncertainties worsen as the cost of dispute resolution or transaction insurance rises and the supply chain's complexity increases. In the end, this could lead to missed business opportunities, lost productivity, missed deadlines, and financial losses in the supply chain.

It is anticipated that the application of blockchain technology in the supply chain will address several challenges, including inefficiencies, visibility and traceability problems, and counterfeit product issues. The distribution, decentralization, encryption, immutability, and smart contract characteristics of blockchain technology make it ideal for supply chain implementation (Madhani, 2021b).

5.24 Overcoming Limitations of Conventional Supply Chains through Blockchain-Enabled Solutions

Information Sharing: Limited information sharing is a characteristic of traditional supply chains. If a company knows where its products are located and how they are doing downstream in the supply chain, or where its raw materials are located upstream, it can be more proactive in spotting and solving possible issues.

Integrating and making information about orders, inventories, and products from outside the company accessible is one of the main issues facing the current supply chain information systems. This data must be in a suitable format and originate from a reliable source. Information systems operating in different technological and operational environments impede the flow of information among participating firms in most supply chains.

All of the participating companies might not be able to afford the costly integration and standardization efforts needed to achieve interoperability among these systems. In order to guarantee the credibility, accessibility, and availability of the data required for supply chain operations, blockchain technology can be extremely helpful.

All pertinent entities within the network can easily access the information, which has been authenticated by the blockchain network. Real-time information sharing between participating Enterprise Resource Planning (ERP) systems is made possible by the blockchain, which acts as an independent layer connecting them. Prominent enterprise resource planning (ERP) vendors are striving to incorporate blockchain technology into their main ERP and other enterprise products to facilitate smooth information exchanges between blockchain deployments in supply chains.

Oracle developed a highly sophisticated and unique distributed ledger-based cloud platform for its enterprise clients after joining the Hyperledger Consortium. In a similar vein, SAP formed the SAP Blockchain Consortium in collaboration with its clients and technology partners to address business issues pertaining to data exchange and digital verification. Implementing blockchain makes it easier for businesses to obtain end-to-end supply chain visibility, which is difficult to do in current supply chain systems without blockchain (Madhani, 2021b).

Time Delays: The hallmarks of traditional supply chains are long lead times and a large number of paper documents. Because of a lack of trustworthy information and regulatory compliance, many supply chain processes, particularly those involving international shipments, require a large number of third-party intermediaries and paper documents. The information needed for verification and compliance procedures can be readily shared by adding the required government agencies and third-party service providers as nodes on blockchain networks. This eliminates the need for paper documents and delays in processing.

In order to investigate the potential of blockchain-enabled systems for coordinating process flows at the delivery points, IBM and the Maersk consortium launched a pilot project for the international shipping process. There were thirty middlemen involved, and 200 pieces of information were exchanged. In the pilot project, all relevant entities took part as nodes on the blockchain platform. The project's outcomes showed notable gains in terms of shorter processing times and less perishable goods waste. Inspired by this pilot project's success, a number of other businesses are experimenting with blockchain-enabled systems to see if they can streamline international shipping procedures.

The largest blockchain-enabled payment network, the Interbank Information Network (IIN), was created and launched by consortia led by J.P. Morgan. It can shorten the time it takes to settle cross-border payments from weeks to hours, which lowers the cost of addressing payment delays (Madhani, 2021b).

Significant Disparities: Table 8 lists the distinctions between traditional supply chains and supply chains enabled by blockchain technology.

Table 8. Traditional Supply Chains Versus Blockchain-Enabled Supply Chains. (Madhani, 2021b)

S. No.	Traditional Supply Chains	Blockchain-Enabled Supply Chains
1.	Information silos due to issues with interoperability of IoTs and ERP systems of the supply chain partners.	Seamless information sharing and data security with blockchain linking the IoTs and ERP systems of the supply chain partners.
2.	Security concerns in sharing sensitive data.	Cryptographic tools ensure the security of information.
3.	Less automation in inter-firm and intra-firm workflows due to information security concerns.	More scope for automation in inter-firm and intra-firm workflows by using IoTs and smart contracts.
4.	Time delays due to cumbersome document verification processes (bills of lading, letter of credit, etc.) at the supply chain delivery points.	Instantaneous access to trustable information leads to faster processes verification. Regulatory processes can be expedited by improving confidence in documentations and hence leads to reduction in wastage, risk, and insurance premiums.
5.	Lack of platforms that connect the supply chain partners and hence require the involvement of third-party intermediaries in trading products and services.	Supply chain platforms enable supply chain partners to connect and trade for the required products and services using smart contracts.
6.	Time delays in cross-border financial settlements due to longer cross-border remittance processes of banks.	Faster cross-border remittance processes with banks and other financial firms participating in blockchain-enabled payment platforms.
7.	Lack of platforms (for enabling collaborative interactions among supply chain partners) due to low trust and security concerns.	Trustable and secured platforms for engaging in collaborative and confidential interactions among the supply chain participants.
8.	Less scope for engaging and empowering supply chain partners.	More scope for engaging and empowering supply chain partners.

Key players in blockchain-based supply chains: Four key players, some of which are absent from traditional supply chains, are involved in blockchain-based supply chains. Registrars: individuals who give each actor in the network a distinct identity. Standards bodies that establish schemes for standards, like Fairtrade for environmentally friendly supply chains or blockchain regulations and technical specifications. Certifiers: people who certify actors to participate in supply chains networks. In order to preserve the trust in the system, actors such as retailers, manufacturers, and customers need to be certified by a registered auditor or certifier (Steiner et al., 2015).

5.25 Elements of Blockchain Technology in Supply Chain Management

1. Blockchain: The principal elements of the proposed blockchain system are as follows:

Blockchain platform: The distributed or decentralized network that houses blockchain applications and data is known as the blockchain platform. Numerous platforms are available, including permissioned blockchains like R3's Corda and IBM's Hyperledger as well as public blockchains like Solana and Ethereum. The selection of a platform is contingent upon particular applications and factors such as security, cost, and privacy of data.

User interface: Through a user interface, various blockchain system participants can communicate with the blockchain and exchange real-time production data. The user interface has two options: it can be linked to intelligent IoT sensors that can upload and record data, or it may directly communicate with a manufacturing management and control system.

The blockchain's creator must also take the accuracy of data uploaded to the network into account. Manufacturing inputs can be verified, for example, with buying and inventory records; production outputs can be readily validated later with inventory and transporting records. To check the accuracy of data, data analytic tools like artificial intelligence can be employed.

Smart contracts: Putting the best-decentralized solution into practice requires the use of smart contracts. In our model, smart contracts are blockchain programs that depend on real-time data. These programs are self-enforcing since they are pre-written on the blockchain platform and unchangeable.

Product digitalization: Production information must be digitalized for information to be exchanged across the blockchain and the real world. Numerous IoT technologies, This can be achieved by using technologies like UPC, QR codes, NFC (near-field communication), and RFID (radio-frequency identification). Real-time production data sharing with the blockchain will be ensured by implementing these technologies on the input materials, intermediate elements, and final items as they are transported, used, or produced.

2. The Suppliers: The suppliers are important blockchain information sources. They can communicate supply-relevant data, including stock updates, transporting records, production progress, and machine/environment conditions, with the supply chain through the integration of the blockchain user interface with their manufacturing and administration systems.

According to the model, since smart contracts may be dependent on this information, suppliers must give the supply chain information regarding the yield of non-defective products. In transactions with other business partners, such as banks or upstream suppliers, suppliers may be able to rely on data shared among them via the blockchain as verifiable records.

3. The Manufacturer: A key participant in both the supply chain and the blockchain is the manufacturer. The manufacturer is supposed to start the smart supply contracts with the suppliers because of its hub position. By significantly lowering intermediate product surpluses and deficits, By exploiting real-time data on the blockchain, these contracts can increase the efficiency of the supply chain.

In addition, the manufacturer communicates directly with the retailer as well as its suppliers. Such relationships provide useful feedback in both directions. With the blockchain, the manufacturer can exchange helpful data about sales, shipping, and faulty parts. Essential input parameters for the smart contracts may be provided by such data. Future product quality improvements can also be facilitated by suppliers with additional information regarding faulty parts.

4. The Retailer: Using the blockchain, the retailer can log sales data and product feedback, including reviews and defects. Since there is no direct relationship between the retailer and suppliers, such feedback can be advantageous to both the manufacturer and the suppliers in particular. Despite the fact that this is unrelated to our supply uncertainty model, it can nevertheless improve the supply chain's overall efficiency (Ma et al., 2022).

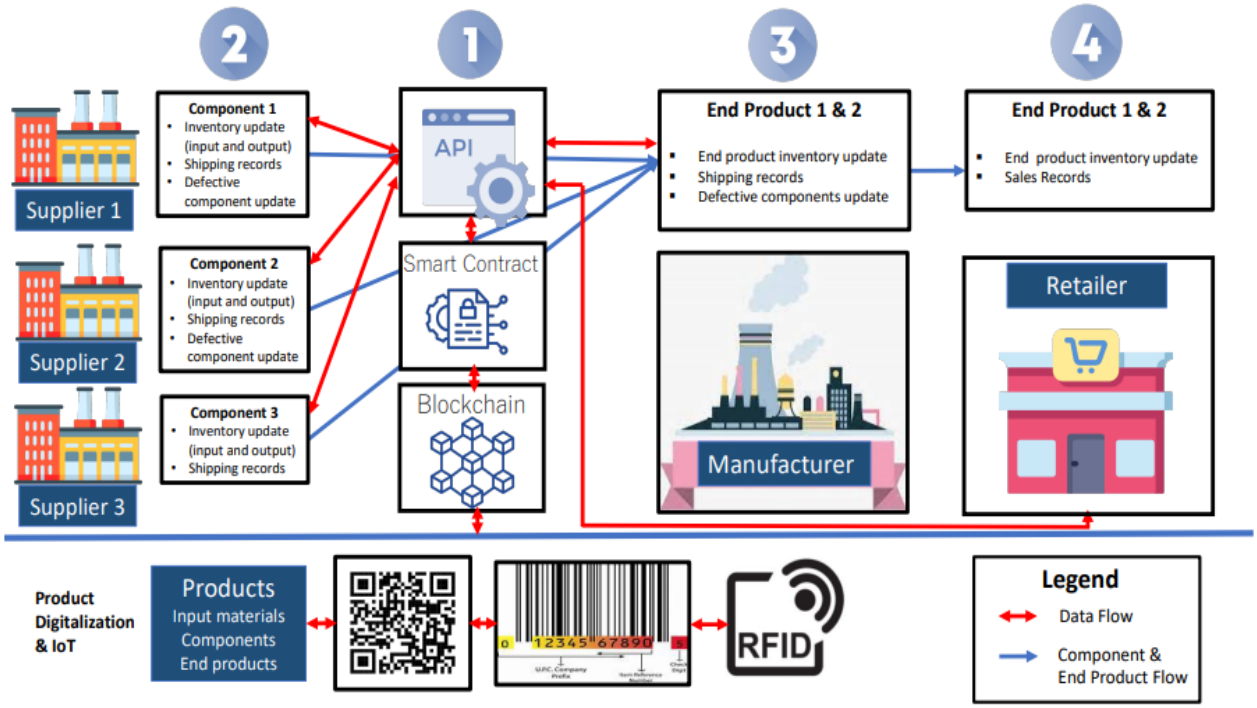

Figure 11. The implementation of a blockchain system. (Ma et al., 2022)

5.26 Blockchain and Supply chain sustainability

While consumers frequently concentrate on the environmental aspects of sustainability, supply chain sustainability entails a more thorough approach that considers social and economic aspects at every stage of a final product's value chain. In order to guarantee dependable management of incoming and outgoing procedures as well as logistics within a supply chain, From a social, environmental, and economic standpoint, supply chain sustainability takes a comprehensive approach. Because there isn't a single, widely-accepted model for gauging sustainability within a heterogeneous global economic network, sustainability standards have grown contentious (Njualem, 2022).

Blockchains, which are community-shared immutable, distributed, transparent, and trustworthy databases, can also have an impact on supply chain networks' sustainability. An important blockchain application area of focus is tracking potential social and environmental conditions that could raise issues with health, safety, and the environment (Adams et al., 2018).

There are real-world examples. In keeping with China's Paris Agreement-related reduction of carbon emissions, blockchains developed in China for carbon asset markets enable businesses to produce carbon assets more effectively3. Human rights and ethical labor practices are better guaranteed in a supply chain that is blockchain based. For example, consumers can be reassured that products they are buying are supplied and manufactured from ethically verified sources when there is a transparent record of the product's history. Smart contracts may be particularly useful for autonomously monitoring and managing sustainable terms and regulatory policies, as well as for enforcing or managing the necessary corrections. Scholars and industry professionals are becoming increasingly interested in sustainable supply chains (Fahimnia et al., 2015).

A more comprehensive and universal view of the supply chain has resulted from focusing on the environmental and social aspects of the chain in addition to the business aspects, which are crucial for sustainable supply chains. The economic, social, and environmental triple bottom lines of sustainability may all be resolved by the promising properties of blockchain technology. As a result, gathering and recognizing instances of sustainable supply chains can serve as an example of the range of applications for blockchain technology. Blockchain technology can facilitate the gathering, storing, and management of data, facilitating the support of substantial product and supply chain data. In this technological context, openness, transparency, neutrality, dependability, and security among every supply chain participant and agent are possible (Abeyrante et al., 2016).

Blockchain technology can facilitate the gathering, storing, and management of data, facilitating the support of substantial product and supply chain data. In this technological context, openness, transparency, neutrality, dependability, and security for all supply chain participants and agents are possible (Abeyratne et al., 2016).

The food and beverage sector is under pressure to maintain a sustainable supply chain. The combination of blockchain technology and radio frequency identification (RFID) to install a traceability system for food in a food supply chain so that food can be tracked in real time using Hazard Analysis and Critical Control Points (HACCP) regulations is an intriguing application in this context (Tian, 2017). According to (Staples et al., 2017), it can document supply chain incidents in the agriculture industry. As only authorized actors are able to record information, blockchain can help supply chains identify dishonest vendors and fake goods, which can seriously harm society.

Adopting blockchain technology can help a company's supply chain from various business aspects that impact their financial performance. In order to bolster the business and financial case for supply chain blockchain technologies, (Saberi et al., 2019) offer a few instances, among many. Blockchains have the potential to disintermediate the supply chain, resulting in fewer tiers that save time and money on transactions, thus cutting down on business waste (Ward, 2017). Blockchain technology minimizes transaction times and human error while instantly sharing any changes made to the data. This could lead to the quick implementation of new products and procedures.

Blockchain technology can guarantee data security and authenticity, which lowers the cost of guarding against willful and arbitrary data alteration that raises supply chain risks and undermines business dependability (Ivanov et al., 2019). In addition, the government and consumers are now requesting supply chain transparency. Forward-thinking businesses realized that transparency offered a competitive advantage (Ward, 2017) which boosts consumer confidence to make larger

purchases and generates financial benefits for the company. Blockchain technology may help ensure the sustainability of social supply chains. Creating stable and unchangeable information is one way to create socially sustainable supply chains.

Because information can only be altered with permission from authorized parties, blockchains can stop dishonest people, governments, or organizations from taking unfair possession of people's assets. Blockchain technology can also stop evil actors and make the corrupt answerable for their personal and societal transgressions. Blockchain traceability contributes to sustainability by improving human rights protection and promoting ethical, secure working conditions. For example, having a transparent history of the product increases a buyer's trust that the products they are buying are ethically sourced.

Blockchain technology can help the environmental supply chain sustainability It can accomplish this from a variety of angles and applications. In order to minimize rework and recall, which lowers resource consumption and greenhouse gas emissions, it is first necessary to accurately track substandard products and identify any additional transactions involving the products. A peer-to-peer network powered by blockchain technology can replace centralized traditional energy systems by minimizing the need for long-distance electricity transmission, which will save a significant amount of energy that would otherwise be lost. Additionally, it would save resources by lowering the requirement for energy storage.

To reduce supply chain waste, a number of blockchain-based power platforms are available, including Suncontract, ElectricChain, and Echchain. Second, blockchain technology could be used to verify the environmental friendliness of products that are marketed as green. Green product processing details are frequently elusive and challenging to confirm. Clients who are concerned about the environment may be more inclined to buy green products if the manufacturing process is confirmed to be low in greenhouse gas emissions. An example of a sustainable Indonesian forest product is a desk from Ikea.

Ikea needs to follow the wood from the point of cutting through the production process to the finished product in order to verify that the desks are actually constructed from this specific wood. Blockchain technology can help manage this intricate process. One such example is the Validation of the Forestry Certifications program, which tracks the provenance of around 740 million acres of verified forests globally using blockchain technology (Rosencrance, 2017).

A further illustration of environmental supply chain sustainability pertains to the carbon tax. It is challenging to calculate each product's carbon footprint in conventional systems. Blockchain technology makes it simpler to track the products of a specific company. It can assist in figuring out how much carbon tax a business should pay. Customers may choose to purchase a low-carbon product if it is costlier and has a larger carbon footprint. Businesses may reassess and reorganize their supply chain in response to this new information and pressure from the market or consumers in order to lower carbon emissions and satisfy customer demand.

By offering the foundations for mapping the supply chain and implementing low-carbon product design, manufacturing, and transportation, blockchain technology can assist in lowering carbon emissions during the product journey. The Supply Chain Environmental Analysis Tool (SCEnAT) presents a methodology for evaluating the carbon emissions of all parties engaged in supply chains and product life cycles. To support industry 4.0 policies, carbon reduction, and green assessments4, SCEnAT 4.0 is a new tool that combines cutting-edge technologies like

blockchain, Internet of Things (IoT), artificial intelligence, and machine learning to manage big data and connect supply chain organizations more successfully.

Blockchain technology has the ability to change the trading of carbon assets. For instance, a blockchain-based platform for green assets is being developed by IBM and Energy Blockchain Labs Inc. in China. It will assist organizations in tracking and measuring their carbon footprint, meeting Carbon Emission Reduction (CER) quotas, and facilitating the development and trading of carbon assets. The transparent, trustworthy, and real-time information provided by the blockchain enables organizations to work together and exchange their carbon assets more successfully in the green asset markets.

Third, recycling can be enhanced by blockchain. Organizations and individuals might lack the motivation to take part in recycling initiatives. By offering financial incentives in the form of cryptographic tokens in exchange for the deposit of recyclables like plastic bottles, cans, and containers, blockchain technology has been used to encourage people in Northern Europe. It is challenging to monitor and contrast the results of different recycling initiatives in the interim. Blockchain enables data tracking for assessing the effectiveness of different initiatives.

For instance, the blockchain-based initiative Social Plastic attempts to decrease plastic waste by converting plastic into cash. Another blockchain app that lets users return plastic containers is called RecycleToCoin (futurethinkers, 2017). The potential of blockchain technology to facilitate closed-loop supply chains makes it a suitable platform for the implementation of emerging concepts like the circular economy.

Fourth, by increasing the effectiveness of emission trading schemes (ETS), blockchain helps the emission trading process. Because of the fidelity and transparency of blockchain, fraud can be prevented through its application. As a result, a reputation-based system is developed to address the ETS's inefficiencies and motivate all participants to devise a long-term plan for reducing emissions. This is made possible by the financial advantages associated with having a positive reputation (Khaqqi et al., 2018).

Difficulties of a supply chain based on a block chain: Implementing Blockchain technology as a mechanism for information management and supply chain governance will be difficult, particularly in a long-lasting network. Long-term and short-term obstacles are common for disruptive technologies (Mendling et al., 2017). Since it may put relationships through the supply chain in jeopardy, participants in the chain must be ready to view it as an opportunity rather than a threat. These illustrations highlight the potential for sustainable supply chains that are enabled by blockchain technology to manage impacts related to the economy, society, and environment (Saberi et al., 2019).

5.26.1 Blockchain Technology's Applications in Sustainable Supply Chain Management

Although blockchain technology is still in its infancy, it has already found many uses in sustainable supply chain management. Here are some instances (Daghighi et al., 2023):

Mineral traceability: The flow of minerals from mine to product can be monitored using blockchain technology. This can guarantee that minerals are sourced ethically and aid in the fight against conflict minerals.

Sustainable fashion: the environmental effects of fashion products can be tracked using blockchain technology. Customers may use this to make more environmentally friendly decisions.

Food traceability: Food products' journey from farm to fork can be monitored using blockchain technology. This can help to ensure food safety and avoid fraud.

Logistics: In the logistics sector, blockchain technology can be used to monitor the movement of products and materials. This may contribute to increased effectiveness and lower emissions.

Recycling and waste management: the transit of recyclable materials can be tracked using blockchain technology. Both waste reduction and recycling rates may benefit from this.

Blockchain technology has the ability to enhance supply chain management that is sustainable, but there are still certain issues that need to be resolved. Among these difficulties are:

Data standardization: In the supply chain, there isn't a single standard for data sharing and collection. This makes tracking the flow of materials and goods using blockchain challenging.

Adoption: In the supply chain sector, blockchain technology is still not well understood or used.

Cost: Since blockchain technology is still in its infancy, implementation may be expensive.

These challenges are outweighed by the potential benefits of blockchain technology for sustainable supply chain management. Blockchain adoption in the supply chain sector is anticipated to increase as the technology develops and implementation costs decrease.

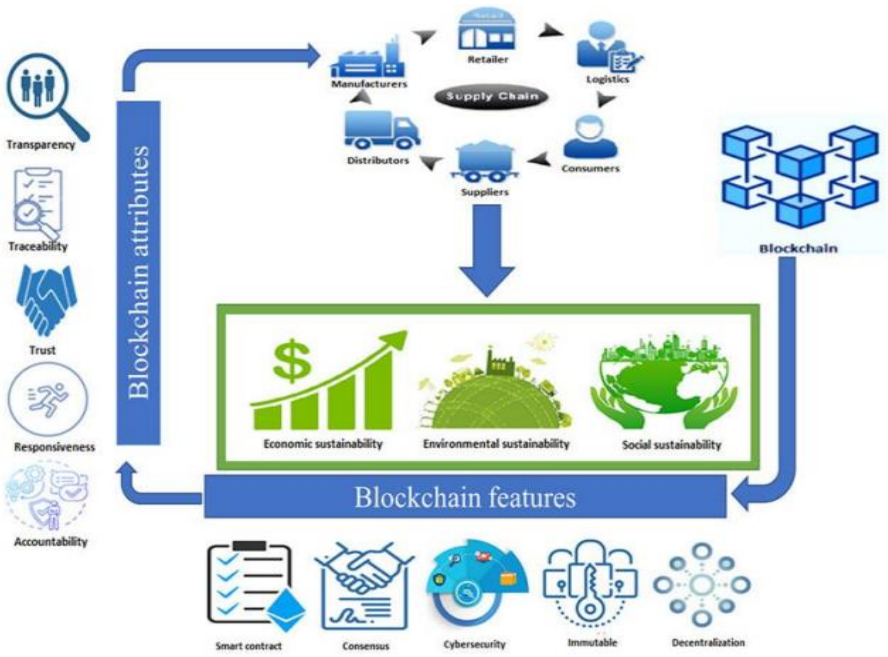

Figure 12. Toward sustainability of supply chain by applying blockchain technology. (Daghighi et al., 2023)

5.26.2 Blockchain Technology's Potential to Enhance Supply Chain Sustainability

The following numerical results show how blockchain technology can be used to increase supply chains' sustainability (Daghighi et al., 2023):

According to a World Economic Forum study, by using blockchain technology, food waste might be reduced by up to 25%. Blockchain technology possesses the capacity to lessen the fashion industry's carbon emissions by up to 30%, according to a study by the Ellen MacArthur Foundation.

According to a McKinsey Global Institute study, blockchain technology could save the logistics sector up to $100 billion annually. Here are some specific instances of how supply chains are using blockchain technology to become more sustainable:

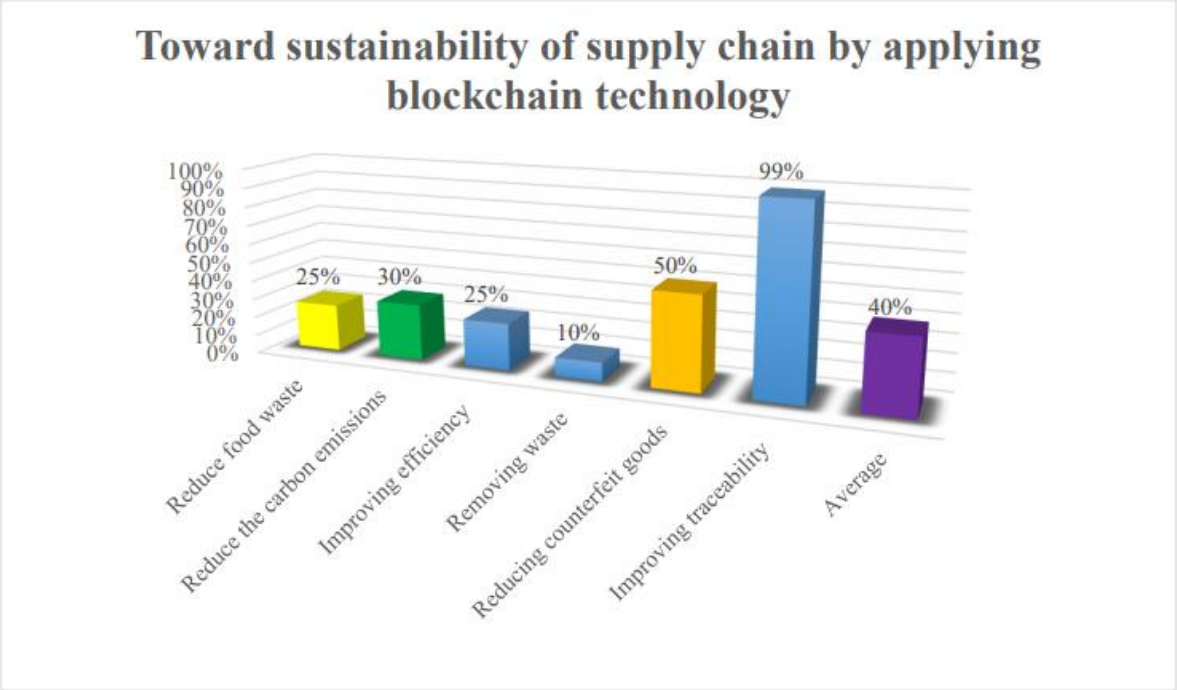

Figure 13. Supply chain outcomes of artificial intelligence application. (Daghighi et al., 2023)

Blockchain is being used by the Gemalto Food Trust to monitor the flow of diamonds. This has made it easier to fight conflict diamonds and guarantee ethical diamond sourcing. Blockchain technology is used by the TextileGenesis platform to monitor the environmental impact of fashion products. Customers are now able to choose more sustainably thanks to this. Walmart is utilizing blockchain technology to monitor the food supply chain from farm to fork. This has improved food safety and helped the company cut down on food waste. To track the flow of goods in the logistics sector, the CargoX platform uses blockchain. Both efficiency and emissions have increased as a

result of this. The following obstacles must be overcome for blockchain technology to be fully utilized in sustainable supply chain management:

Data standardization: The supply chain's methods for gathering and exchanging data are not standardized. Because of this, tracking the movement of materials and goods using blockchain is challenging.

Adoption: In the supply chain sector, blockchain technology is still not well understood or used.

Cost: Since blockchain technology is still in its infancy, implementation may be expensive.

Blockchain technology's possible benefits for environmentally friendly supply chain management outweigh these difficulties. The supply chain industry is anticipated to adopt blockchain more widely as the technology develops and implementation costs decrease (Nevisi et al., 2023; Asgari-Motlagh et al., 2019).

5.26.3 Some of Blockchain Technology's Impacts on Sustainable Supply Chains

Traceability: Using blockchain technology to track materials and goods while they proceed along the supply chain can help to detect and cut down on waste. For instance, a World Economic Forum study discovered that blockchain technology could reduce food waste by as much as 25%.

Security: Data protection and fraud prevention are two benefits of using blockchain technology, which is secure. This is critical to maintaining the supply chain's integrity and averting losses. For instance, a McKinsey Global Institute study discovered that blockchain might save the logistics sector up to $100 billion annually.

Transparency: Blockchain enables information about the supply chain to be shared with all parties involved, which can foster cooperation and trust. Decision-making and operational efficiency may increase as a result. For example, an investigation carried out by the Ellen MacArthur Foundation found that blockchain technology may cut the fashion industry's carbon emissions by as much as 30%.

Efficiency: A large number of the manual supply chain management procedures can be automated by blockchain, which can result in time and cost savings. For instance, a University of Cambridge study discovered that blockchain might lower trade finance costs by as much as 20%.

Considering the above in order to negotiate better quantity discounts, blockchain technology applications can assist in tracking the purchase activities of the organizations. Through precise demand forecasting and supply chain resource management, blockchain technology assists organizations in mitigating the risk associated with supply chains. blockchain technology is able to keep an eye on and verify the manufacturing parameters in the manufacturing domain. Data-driven, Industry 4.0 technologies produce vast amounts of data that are needed to make wise decisions. The big data produced by industry 4.0 technologies can be utilized with blockchain technology. Better process documentation results from the integration of additive manufacturing with blockchain technology, which enhances the features of the product design.

By standardizing and distributing the quality documentation procedures throughout the supply chain, blockchain technology can increase the efficiency of the participants. Wipro has created a blockchain technology application to detect and remove fake goods, offering a high degree of

product transparency. Vehicle surveillance and freight management are two major ways that blockchain technology can help with logistics and transportation. The organizations are aware of the advantages that blockchain technology offers, but a full-scale implementation in the supply chain is still some distance ahead. According to (Angelis et al., 2019), the value that Blockchain will bring to an organization should take precedence over the exaggerated claims made about its advantages when it comes to adoption decisions (Kamble et al., 2023).

5.26.4 Adoption of Blockchain Technology, Integration in Supply Chain, and Sustainable Supply Chain Performance

There is a lack of accountability and transparency in a supply chain network due to the large number of performers involved. As a result, Blockchain Technology, the industry-leading technology developed within the framework of the digitalization of the supply chain, improved product traceability, safety, and transparency while also lowering costs and enhancing Sustainable Supply Chain Performance.

Additional advantages of blockchain technology include enhanced financing procedures, fraud prevention, privacy, cyber-security, and protection, as well as increased accountability and auditability. Improved sustainable supply chain performance and closed supply chain relationships are found to be largely dependent on the degree of trustworthiness provided by the blockchain technology-enabled supply chain.

Through the digital integration of numerous stakeholders, blockchain technology enables supply chains to benefit from product traceability, transaction settlement, process automation, and smart contract execution. One of the main characteristics of blockchain technology is information integration, according to (Polim et al., 2017). The supply chain integration that blockchain technology offers is extremely secure and guards against unauthorized access to the data kept on the ledger. Hyper-levels of supply chain integration that integrate customer, supplier, and customer information are made possible by blockchain technology (Kamble et al., 2023).

According to (Kshetri, 2018), combining Blockchain with IoT can help locate the source of supply chain disruptions and effectively handle crises like product recalls. Reducing uncertainty through comparable blockchain technology integration with other emerging technologies will improve supply chain transparency, process integration, and traceability. Blockchain improves supply chain operational efficiency, privacy, and auditability. The performance of a sustainable supply chain is impacted by the level of integration within the supply chain. Supply chain integration is suggested as a significant mediating variable in the recent studies examining the impact of ICT-enabled integration technologies on Sustainable Supply Chain Performance, such as IoT and supply chain information systems (Kamble et al., 2023).

Well-known for its capacity to handle vast volumes of data, Machine learning concentrates on developing intricate algorithms capable of learning from previous experiences and refining themselves autonomously (without explicit programming). This has led to amazing advancements in the field of effective decision making, as it can recognize patterns and derive conclusions from verifiable evidence. The combination of blockchain technology and machine learning presents a chance to leverage blockchain's decentralized architecture to create more effective predictive algorithms for supply chain sustainability (Sahoo et al., 2022).

Just a single review explicitly investigated the relationship between blockchain technology capabilities and supply chain sustainability, albeit in a limited manner, and only a small number of reviews attempted to investigate this relationship. Issues with counterfeits, data security, and privacy, operating costs, and bureaucratic roadblocks in the circular economy domain can all be effectively resolved with blockchain and smart contracts (Centobelli et al., 2022; Sahoo et al., 2022).

After reviewing the items mentioned above, we will briefly discuss the performance of the sustainable supply chain in the automotive sector.

5.26.5 Sustainable Supply Chain Performance in the Automotive Industry

Acccording to (Kamble et al., 2023) a sustainable supply chain Success in the operation of an organization is largely dependent on performance. Planning, executing, and monitoring strategies are aided by the prompt and effective supply chain assessment. Tracking down the events is becoming a major challenge due to the supply chains' expanding activities and scope. Should the supply chains exhibit transparency and furnish information regarding the diverse historical incidents associated with the products and services, buyers and customers will recognize the true worth of the offerings. The supply chain must change its current interdependencies with its partners to become a digital eco-system, and it must grant all participants access to its information.

For shared responsibility and collective value creation to be successfully integrated, each supply chain partner becomes equally important. Most prior research on sustainable supply chains has emphasized the economic, environmental, and social dimensions of sustainability.

In order to emphasize enhancing the automotive supply chain's financial performance and proving its long-term soundness, (Kamble et al., 2023) concentrated on economic sustainability in their study. In their study, they place less emphasis on the short-term objectives of increased productivity and profitability and more on the capacity of organizations within the automotive supply chain to achieve high financial performance over the long run. Accordingly, the study's definition of economic supply chain sustainability is the systemic and strategic coordination between various business functions that drives an organization's enhanced financial performance and the supply chain.

The supply chain is handled holistically in the study, taking into account the important roles that suppliers and customers play in achieving supply chain integration. It concludes that the ability of the supply chain partners to adjust to changing environmental dynamics is an important part of sustainable supply chain performance. Consequently, the dynamic and intricate character of contemporary supply chain networks is being challenged by technological advancements in digitalization, which calls for a higher level of dynamic capabilities (DC) in the supply chain. Because Sustainable Supplychain Performance and DC share comparable organizational and environmental circumstances, it makes sense to apply DC concepts to the field of Supplychain Performance.

In addition, companies that pursue a sustainability strategy are more vulnerable to unforeseen events than those that do not. In these kinds of settings, stronger players are more likely to penalize companies that violate their sustainability standards. The worst situation is when these specifications are altering quickly and in an unpredictable manner. Because of this, supply chain performance and sustainable supply chain performance address the dynamics that a globalized

world has infused into organizations. These dynamics include highly vulnerable logistic networks, globalized competition, and nearly instantaneous digitalization and information-sharing capabilities. These elements comprise the highly dynamic environment the dynamic capabilities concept is meant for (Kamble et al., 2023).

5.27 Blockchain and Supply chain transparency

The three primary problems in the supply chain, according to (Awwad et al., 2018), are demand management, data visibility, and process optimization. The supply chain can be made more efficient by incorporating blockchain technology. Putting blockchain into practice can address the primary issue of data visibility. Transparency and trust are the two most crucial elements in creating a strong link in the supply chain, and blockchain can act as a bridge to help foster these relationships.

Among digital technologies, blockchain is one of the newest and fastest-growing ones that can support sustainable manufacturing. A distributed and decentralized data structure is what blockchain technology offers. On a peer-to-peer, open access network, data are shared, and transactions must be approved, validated, and accessible by network community members. Blockchain makes sure that transactions are secure and transparent. Blockchain was initially applied in the banking industry to replace human transaction authentication with digital authentication for cryptocurrencies (Khanfar et al., 2021).

Blockchain has drawn interest from experts in a variety of fields as well as scholars because It might enhance the security of data, immutability, traceability, transparency, and trust. The amount of money invested in blockchain solutions is predicted to increase quickly, reaching USD 176 billion by 2025. The manufacturing and supply chain sectors can enhance their practices for economic, social, and environmental sustainability by making use of blockchain technology's exciting potential. The importance of sustainability to the manufacturing sector has sparked an increasing amount of scholarly interest in the ways that blockchain technology might enhance the sustainable performance of manufacturers (Khanfar et al., 2021). Now, considering the above we will go deeper in the subject.

5.27.1 Blockchain Technology in Supply Chain Management: Enhancing Transparency

The supply chains of todays are intrinsically complex, with multiple tiers and geographically dispersed entities striving for customers' business (Saberi et al., 2019). Supply chain risk management and information evaluation are extremely challenging due to government regulations, cultural diversity, globalization, and human behavior differences. Such risk can be mitigated by improved information sharing and verifiability. Inefficient transactions, fraud, pilferage, and subpar supply chain management are the main causes of this risk.

Paper documents and receipts, which are easily misplaced or altered, are the primary means of transaction for luxury and high-value goods in traditional transactions. Supply chain participants and consumers cannot confirm and validate an item's actual value when the supply value of that item is opaque. Managing traceability in the supply chain is made more difficult by the expense of reliably handling such transparency. These problems raise concerns about whether the current

information systems can facilitate obtaining the data needed for the prompt origin of goods and services in a safe manner that is reliable and strong enough (Saberi et al., 2019).

Supply chain management and logistics is being significantly impacted by blockchain technology because it offers a decentralized "trustless" database that enables international transactions and decentralization among different supply chain participants. These days, supply chain managers are starting to recognize this new technology's potential, which has enormous promise for enhancing supply chain transparency (Sivula et al., 2021).

Blockchains increase the transparency of the supply chain, which enhances sustainable performance. The degree of information that counterparties in an exchange and external observers, such as organizational and environmental contexts, can easily access is known as transparency. In the context of supply chains, transparency pertains to information that is easily accessible to end users and businesses involved in the chain (Bai et al., 2020).

The degree to which supply chain participants can access and share information about products and processes without interruption, noise, delay, or distortion is referred to as supply chain transparency. Transparency has a strong connection with visibility and traceability.

The scope of transparency has been defined in a variety of ways. Business transparency is the provision of full, timely, and accurate information; it also promotes stakeholder honesty, enhances teamwork, and facilitates group decision-making. Supply chain transparency contributes precise information regarding operations, operations, and commodities, including their source and origin, methods of processing, and logistics. Process transparency pertains to the policies implemented by an organization to guarantee that information is not only obtainable, usable, comprehensible, and presented, but also provided to all relevant parties. The ability to quickly access and manipulate data, independent of its location or the application that created it, is known as data transparency.

Apart from being an essential component for supply chain participants, traceability promotes transparency by offering transparent and readily accessible data regarding a product's attributes, an indication of location of origin, movements, procedures, and ownership. It's also important to note that supply chain processes may be considerably more transparent thanks to traceability systems. It is stated that supply chain transparency preceded supply chain visibility (Sunmola et al., 2023).

Enhancing the precision of data in blockchain-based transparency systems requires visibility, which concentrates on particular supply chain processes and outcomes like sustainability performance as well as data sharing. One of the most significant applications of blockchain technology is to increase trust, and transparency is probably a prerequisite for trust. By employing strategies such as smart contracts to eliminate the need for intermediaries in the supply chain, blockchain technology also provides a trustless approach. Cost reduction and savings have been viewed as essential success factors for ensuring the development and maintenance of transparency systems. By allowing information to be freely shared throughout the supply chain, transparency can reduce costs. It can also help to improve forecasts and inventory levels, which will improve performance (Sunmola et al., 2023).

As we reviewd above companies must first make investments as a requirement for supply chain transparency in supply chain visibility. They need to lay out their supply chain processes first. After that, they must complete commissioning reports, supplier interviews, and audits. The

financial benefit of this supply chain visibility investment comes from better operational decision-making. The needs of internal stakeholders in the business (or its supply chain), such as managers, direct suppliers, or customers, are met by visibility. Transparency, on the other hand, focuses on a larger range of external stakeholders, such as investors, monitoring organizations, consumer rights advocacy groups, and NGOs (Sodhi et al., 2019).

Over the last few years, blockchain has gained prominence in the business world and is increasingly being acknowledged as a game-changer for numerous industries, including the manufacturing, financial, and service sectors. Making supply chain management more efficient becomes crucial due to its unique features, which include privacy, security, smart contracts, scalability, and the capacity to resolve the double-spend issue. The use of blockchain enhances the privacy, tracking, transparency, and enforceability of smart contract transactions involving two or more parties. The supply chain system becomes more cost-effective, high-performance, and energy-efficient over time with the use of blockchain technology. Utilizing blockchain technology can increase productivity and make better use of available resources; additionally, this cutting-edge technology will support the establishment of a sustainable supply chain.

Researchers and business professionals are attempting to apply blockchain, an emerging technology, in the supply chain. Not much research has been done because this technology is still in its early stages of development. Through a retailer or supplier, blockchain assists in controlling costs and ensuring transparency, security, and traceability from the producer to the end users. Regarding food production, organic food, and an improved food life cycle are supported by sustainability certifications and standards. These kinds of mishaps give rise to new technologies in the supply chain and manufacturing. The benefits of using blockchain are distributed, accurate, transparent, irreversible, and secure. The integration of blockchain in supply chain management will be motivated by all of these kinds of requirements (Yadav et al., 2020).

Lastly, information sharing with shareholders, customers, consumers, trading partners, and regulatory agencies is a component of supply chain transparency. Transparency cannot be achieved without traceability since it satisfies legal criteria, assesses supply chain efficiency, and validates sustainability claims. Modern supply chain projects use various technical solutions to achieve traceability. However, data transparency may be compromised by lack of trust among partners, requiring more solid trust to be developed. Internet of Things (IoT) technology can help build trust by offering transparency across the chain, such as tracking things back to their source. Nevertheless, more data loads inside the partners' separate systems limit the supply chain (Hellani et al., 2021).

5.27.2 Blockchain in supply chain, Transparency and Visibility

Fraudulent transactions, stealing, a lack of social responsibility, and subpar environmental performance are all possible problems for modern supply chains. Improving the supply chain's visibility is a crucial tool for addressing these issues and worries. Enhancing supply chain transparency and contributing to the mapping of supply chain networks, along with disseminating accurate, dependable, and secure information about supply chains and sustainable practices, can all help to raise visibility. Transparency then offers chances to improve the global supply chains' social and environmental sustainability.

Supply chain partners must encourage transparency; those who do not uphold these standards will lose market share, relationships, and reputation. Encouraging supply chain sustainability and transparency, however, is a difficult task that requires careful consideration, particularly in the supply chains for agriculture in developing countries. The advent of the fourth industrial revolution has led to the emergence of a number of new, disruptive digital technologies that aim to improve supply chain transparency, authenticity, and information efficiency.

Accurately identifying and gathering data from every supply chain link is known as visibility, or traceability. A crucial element of supply chain managing is tracking a product's journey through the supply chain. Disclosure is the exchange of information at the required or expected level of detail both internally and externally (Bai et al., 2022).

Blockchain greatly aids sustainable supply chain management by offering visibility and transparency of supply chain exchanges between supply chain partners and focal firms while safeguarding their privacy. Blockchain technology can be used to establish an electric power supply marketplace. Rooftop photovoltaic solar panels can be used for microgeneration of electricity, this can encourage the use of renewable energy sources and replace conventional energy sources. In particular, smart meters can be used to record on a blockchain the amount of electricity generated and consumed by each grid user. Credits can be repaid for power consumption as well as incentives given to users for surplus power supply.

This provides an easy, transparent, and dependable peer-to-peer trading mechanism for energy supply networks in the infrastructure sector. To lower the carbon footprint of supply chain activities, companies can benefit from decision-support tools that use predictive algorithms created using machine learning techniques. These systems can be coupled with blockchain technology to guarantee transparency and traceability between partners in supply chain throughout industries.

Specifically, supply chain in the food industry may benefit from blockchain implementation, particularly in conjunction with genome codification and reports on nutrient sampling. Furthermore, end users can benefit from traceability and transparency when Quick Response (QR) codes or Radio Frequency Identification (RFID) tags are used on finished products. These tags can contain information about the origin of particular components as well as details about manufacturing conditions and distribution (Sahoo et al., 2022).

Finally, according to (Rogerson et al., 2020) blockchain has the potential to provide supply chains with the upstream visibility that customers are demanding. For instance, it can log information on whether a particular fish has been legally caught or whether a particular diamond has been legally mined. This is primarily because of the technology's decentralized, consensus-based trust mechanism, which promotes simultaneous immutability and transparency to help with the performance management of important supply chain management processes. By allowing stakeholders to view timely, accurate, and reliable information and minimizing the number of data sources that contribute to decision points, the visibility offered by blockchain solutions facilitates decision-making.

5.27.2 Block chain, Supply chain transparency and sustainability

Transparency in supply chains and sustainability are related in a number of ways. First, the supply chain's sustainability may be enhanced by its transparency. For instance, businesses can more readily adopt procedures based on open information to satisfy stakeholders' long-term needs and foster confidence. Second, in order to be sustainable, businesses must act responsibly and transparently and submit to public scrutiny.

For example, in order to meet legal obligations and acknowledge the supervision of external personnel, businesses must disclose sustainability information. Third, suppliers' sustainable performance can be greatly enhanced by supply chain transparency. To increase supply chain sustainability, companies like Apple and Nike, for instance, use supply chain transparency to voluntarily reveal the list of suppliers to the public.

Companies such as Walmart have discovered the benefits of blockchain technology-enabled food product traceability, particularly for wheat and soybeans. They are able to locate the source of contaminated products and proactively provide safety inspections.

Regarding how to make the supply chain sustainable and transparent, there is no agreement. Nevertheless, developing novel technologies presents a powerful ability or tool. Big data analytics, blockchain, the Cloud, and the Internet of Things (IoT) are some of these disruptive technologies. Blockchain technology has emerged as a potentially essential tool for businesses to manage the risks and complexity of increasingly complex global supply chains. It may additionally offer the visibility that is required to satisfy the requirements of stakeholders for sustainable supply chain transparency (Bai et al., 2022).

The majority of studies contend that because blockchain technology allows for the accurate sharing of data among numerous participants, it is the most useful instrument for promoting supply chain sustainability and transparency. Additionally, blockchain can facilitate inventory visibility, which lowers the possibility of waste. It can contribute to sustainable supply chain transparency with its smart contract capabilities.

For instance, the Ethereum platform tracks fish from fishermen to distributors along the supply chain, making it the initial blockchain transparency application from a sustainability standpoint through the use of smart contracts. Blockchain technology is expected to usher in an extremely transparent and sustainable era for the global food system, providing hope to the agriculture supply chains.

Blockchain technology is being used across numerous agricultural supply chains to increase sustainability and transparency. Nestle, for instance, uses blockchain technology to enable supply chain tracking. Starbucks has created a mobile application that provides information about the coffee supply chain, including where the coffee comes from, how it is roasted, and how the company supports local farmers.

In order to achieve traceability, Tony's Chocolonely successfully conducted a six-week blockchain pilot in February 2018 in partnership with Accenture. A British company called Gaiachain worked with Nitidae to design a blockchain-based traceability system for the cocoa supply chain in Africa. This system can decrease fraud, lower transaction costs, and boost manufacturing margins of profit in an environmentally friendly manner. Finally, there is good news regarding improved SSCT using blockchain technology.

Conclusively, the authors suggested that sustainable supply chain transparency consists of three dimensions, per (Bai et al., 2020): (i) The spectrum of transparency, encompassing elements like the extent of supply chain partner participation, the range of activities, and environmental and social data; (ii) Product transparency, encompassing the tracking of product components (like the origins of raw materials), the tracking of product processes (from the point of origin to the final consumer), and the tracking of product sustainability data (like carbon emissions and recycling); and (iii) The participant transparency, featuring visible participant operations, situational information, and sustainability conditions.

5.27.3 Block chain for supply chain transparency and traceability

By using verifiable records and labeling, traceability helps to demonstrate the transparency of the supply chain. Traceability serves as a link to identify, validate, and isolate sources of disagreement with established standards and customer expectations, thereby increasing the overall financial value of the quality management system. Because businesses are growing to meet the population's increasing demand, the global supply chain is becoming a complex web, and traceability has become increasingly important.

According to Sanjay Almeida, chief product officer of Network Solutions for SAP, blockchain's distributed trust and transparency enable more people to join supply chain networks in a hassle-free manner. The excellent tracking of products from the point of origin to delivery will be made possible by the integration of blockchain technology with a variety of tracking devices, ensuring the legitimacy and reliability of the entire process. One of the main advantages of blockchain technology for management is the fact that it offers a better and more preferable way to pinpoint the precise problem and its location (Awwad et al., 2018).

Provenance is the process of creating a system of traceability for goods and materials using blockchain technology. This system can store information that is open, unchangeable, and auditable by nature, allowing anyone to observe the provenance of any object. Provenance tracks tangible goods and confirmed attributes from the place of genesis to the selling point using blockchain technology in conjunction with mobile devices and smart tags. Provenance tracks tuna fish caught in Maluku, Indonesia from the point of landing to the factory and back using peer-to-peer blockchain technology.

This demonstrates how supply chain traceability and transparency may be enhanced by blockchain technology. Blockchain technology is not just used in finance and cryptocurrency; one area where it is most likely to have a significant impact is supply chain operations. Because of its speed, transparency, immutability, and efficient performance and outcome measurement, blockchain technology can count the problems that traditional supply chain management faces. (Awwad et al., 2018).

5.27.4 Challenges and Processes in Achieving Supply Chain Transparency

The current global supply chain is made up of a complicated web of industry-spanning stakeholders who work together to coordinate tasks and reach agreements. The key supply chain obstacles are shown in Figure 14. and include centralized systems, an abundance of

transparency, scalability issues, difficulties integrating IoT, and emerging technologies. Technical Supply Chain Difficulties, Figure 14. in addition to the excellent integration of new technologies, the current centralized supply chain systems labor ineffectively to provide just a few of the essential requirements through workarounds and reliable third parties. These independent databases suffer from a lack of trust, which has led to unsatisfied and negative customer reviews.

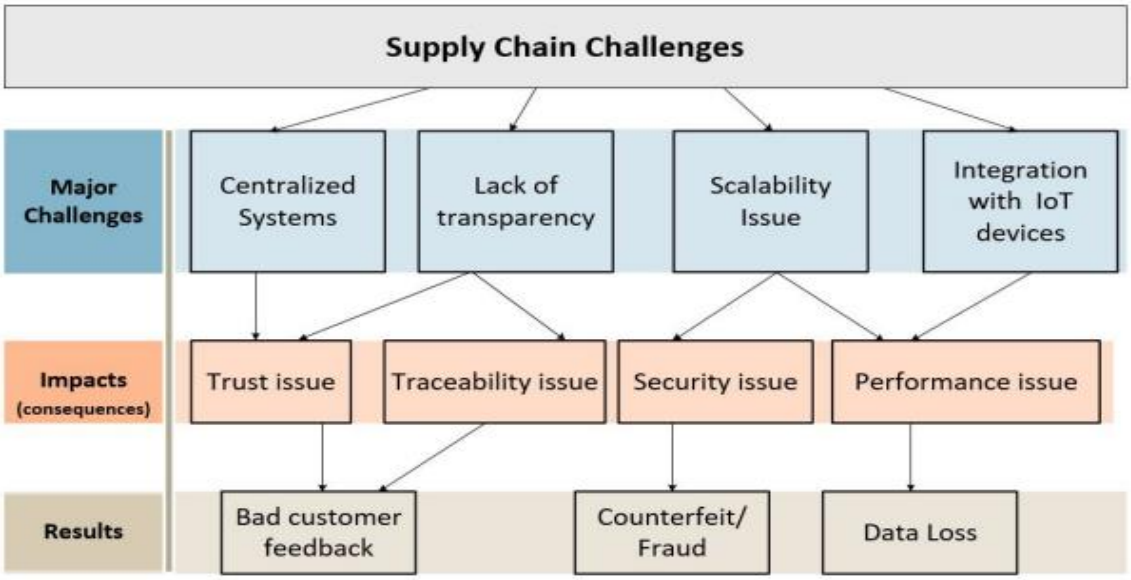

Figure 14. Technical Supply Chain Challenges. (Hellani et al., 2021)

The primary transparency problem with a centralized system is that most of the supply chain lacks trustworthy shared information. Negative customer feedback, trust issues, and traceability are all caused by a lack of transparency. Furthermore, when the product is used in multiple geographical locations, scalability becomes a significant issue. It includes important documents like invoices, customs paperwork, ISO certificates, letters, proofs, and so on, and necessitates hundreds of conversations between parties. According to a study, 200 communication procedures are required to deliver a single product. Therefore, performance and security problems arise as a result of scalability issues. As a result, these lead to data loss and, frequently, counterfeits in the intended product data.

Customers may become dissatisfied as a result, and partners may develop trust issues. Furthermore, the centralized conditions of the present network infrastructure make it impossible to fully utilize IoT and handle/analyze the massive influx of data. This eliminates a significant amount of the power of the Internet of Things. Presently, there exist untrustworthy structures and networks intended to link billions of diverse and heterogeneous Internet of Things devices and the services they offer, along with data collection and analysis (Hellani et al., 2021).

5.27.5 Leveraging IoT for Enhanced Supply Chain Transparency

(Hellani et al., 2021) Believe that as IoT technology advances, so does the significance of integrating IoT with Blockchain to improve supply chain transparency and traceability. Compared to manual methods, the IoT devices' salient features include the ability to collect precise data, adapt quickly, and provide always-on availability services. IoT finds it challenging to establish true cooperation under the current central structure since the relevant parties to such cooperation frequently belong to different vendors with convoluted or ambiguous trust relationships. As a result, currently available IoT devices are able to function together in a secure environment.

Blockchain can guarantee the veracity of data on the network because it is a technology that provides a trusted service. Information efficacy is guaranteed by IoT when it is uploaded directly from the source. When IoT and blockchain are combined, there are countless innovative possibilities. It is mainly useful for monitoring the history of various products. IoT technology is thus crucial for innovative business systems. Furthermore, because IoT devices are the tangible interfaces that gather data, they contribute to the development of a positive connection between the Blockchain and the outside world.

Table 9. IoT-enabled DLT-based supply chain projects. (Hellani et al., 2021)

Project	IoT Technology	IoT Role	Technology Base
Modum	Modum temperature logger	Trace drug temperature instantly	Smart contract and BLE
WaltonChain	IOT-RU20 (RFID tag IC and reader IC)	Upload data direct to Blockchain and realizes Anti-counterfeit	UHF Android Smart RFID Reader/Writer
Vechain	Encrypted chips tag technology development	Monitor and trace	Adds ID and asymmetric keys to IoT devices
Wabi	Walimai	Links digital and physical assets through RFID labels	Secure RFID label Authentication is done through mobile consumers
Everledger	Intelligent Labeleing	Links digital and physical assets through RFID, NFC,	NFC, RFID beacons, and synthetic DNA

Furthermore, IoT technology can guarantee the true efficacy of the data by minimizing the disruptive elements at the source. In the industrial field, five IoT techniques are primarily used. Cloud computing, middleware, RFID, wireless sensor networks (WSN), and Internet of Things software. IoT techniques, as opposed to human abilities, help producers accurately collect data, including the ability to sense temperature variation, calculate elapsed time, and determine color degree. As demonstrated in Table 9, numerous initiatives use IoT technology to enforce supply chain transparency. Every project makes a different use of this technology.

Waltonchain has a close relationship with the person who created RFID technology. It presents an improved RFID version for a supply chain based on blockchain technology that offers the business system tamper-resistance, dependability, anti-counterfeiting, and traceability. Thus, the

Waltonchain project offers an RFID tag IC and reader IC that are suitable for Blockchain applications in addition to Blockchain features.

The elliptic curve algorithm and decryption acceleration module, which are integrated into the ICs, are based on the current RFID technology and include an interface for communication protocol for Blockchain apps. Major IoT issues are resolved by Waltonchain in blockchain-based applications.

Tags are not stored with data, and their only duty is to verify signatures. In order to guarantee the uniqueness, authenticity, and resistance to tampering of the IoT application tag, tags automatically produce random public keys and private keys. As a result, tags can help address data overload in Internet of Things applications by storing less data.

Additionally, tags address the issue with asymmetric encryption technology's slow encryption and decryption. Another RFID Internet of Things gadget, the Modum logger temperature, is made by Modum. The logger is an Internet of Things temperature sensor intended for use with medical supplies that don't need to be actively cooled while in transit. The observed temperature is recorded in the logger memory during the shipment process.

It is possible to check the shipment without opening it by using Bluetooth technology. Each evaluation's findings are kept in an immutable smart contract within the Blockchain. The integration of IoT, Bluetooth, and smart contracts shows that pharmaceuticals have not been subjected to circumstances that could jeopardize their integrity and quality.

Vechain uses an asymmetric key algorithm to add personal identification to a traditional IoT component, upgrading its chip layer. It creates 20-byte random IDs, hashes them, and converts them into Every piece of IoT equipment is thus uniquely identified by its asymmetric key and ID. These IDs are kept permanently on the Blockchain and are controlled by smart contracts.

The same objective can be accomplished using various technologies. IoT and blockchain technology are of interest to both Wabi and Everledger in order to connect digital and physical assets. They do, however, employ various IoT tag devices (Hellani et al., 2021).

5.27.6 Blockchain’s Smart Contract for Supplychain Transparency Enhancement

(Hellani et al., 2021) found out that the intricate networks of manufacturing pose a challenge to the transparency of the supply chain and have an impact on the overall system of collaboration. The collaboration can be arranged and the transparency gap can be reasonably addressed by the smart contract. Apart from its pivotal function in drafting legal agreements among Blockchain participants, a smart contract also ensures the tracking and surveillance of the data content intended for the product.

Smart contracts are used by a few of the supply chain projects based on blockchain technology that are included in Table 10 to increase transparency. Depending on their infrastructure requirements, they integrate it differently.

Table 10. Transparency techniques of supply chain DLT-based Projects. (Hellani et al., 2021)

Project Name	Transparency Technique	Tool
Ambrosus	Merkle Tree Algorithm	Hash-based data structure
	Smart contract	Measurement and requirement smart contracts
Modum	IoT device involvement	"track and trace" QR code
	IoT device involvement	Modum temperature logger
	Smart contract	Normal utilization
Vechain	Blockchain core improvement	Block transaction format (ID, DependsOn, Blockref)
	Smart contract	Normal utilization
Chronicled	IoT device involvement	Smart tag (cryptographically secured chip)
WaltonChain	IoT device involvement	RFID tag IC
	Smart contract	Manage parent chain and sub-chains contracts
Devery	Smart contract	Smart contracts for registration and verification
OriginTrail	Smart contract	Off-chain utilization
	Zero-Knowledge Proof	Sensitive data protection
Cargocoin	Smart contract	Normal utilization
Bext360	Smart contract	Normal utilization
Shipchain	Smart contract	Normal utilization
WABI	IoT device involvement	RFID cryptographically secured chip
TE-Food	IoT device involvement	Plastic security seals (1D/2D barcodes)
	Smart contract	Normal utilization
FarmaTrust	Smart contract	Normal utilization
	IoT device involvement	QR code scanner via mobile SMS/voice label code on traditional mobile
ProductChain	IoT device involvement	Transaction vocabulary
BlockGrain	Smart contract	Public/private Blockchain managment
Zero defects	Blockchain core improvement	IOTA DLT platform
Everledger	IoT device involvement	Inteliggent Labelelling: RFID, NFC
FR8	IoT device involvement	Combines RFID, ID, product information

By putting forth a framework that links smart contracts and the assets of the manufacturing supply chain, (Dietrich et al., 2020) suggest using smart contracts for transparency. According to their proposal, a specific smart contract that is kept on the Blockchain is generated for each asset, giving it a unique identification number. As a result, the Blockchain ledger can be thought of as a timestamp database that anybody can use to determine when a particular event has happened. By introducing two distinct types of smart contracts measurement and requirement Ambrosus incorporates smart contracts in an innovative way. The smart contract necessities identify whether

a product constantly fulfills the standards specified by an interested network participant. Every asset and guidelines are frequently used in the measurement contracts.

The Measurements Smart Contract items are directly compared to the smart contract, which is used in this framework as a new protocol to establish quality standards. Vechain leverages the built-in extensions on contracts known as built-ins, along with the Ethereum virtual machine (EVM). Six smart contract extensions are included to increase the data's reliability. The incompatibility of stakeholders' rules and conditions generally leads to challenges in reconciling transparency requirements, which in turn complicates the process of achieving transparency. The partners face the challenge of achieving the desired transparency without disclosing personal information. Transparency and a certain amount of data privacy can be achieved with the help of a reliable smart contract.

To determine the risks and goals, all applicable regulations, standards, and conditions about various supply chain partners must be gathered at the outset. Therefore, on the immutable Blockchain ledger, a smart contract transcribes/records and keeps all the terms, conditions, and risks. It is dedicated to carrying out the partners' advice by assiduously and logically adhering to their predetermined code content. Subsequently, the smart contract can aid in fulfilling the planning requirement and help it accomplish its goals.

Connecting IoT technology to smart contracts allows for direct communication with sensors to guarantee accurate execution. Since the registered data is kept on an official ledger, it serves as a source of confidence for each and every partner. Ultimately, decisions about data exposure are made via a reliable and dynamic platform that takes into account the intricate network of the supply chain.

5.27.8 Transparency Versus Obscurity: Access Governance

Additional challenges exist that could impede the attainment of complete transparency. The opacity and privacy demanded by stakeholders who want to conceal sensitive information like plans, costs, secret ingredients, etc., are at odds with full (uncontrolled) transparency. Since its inception, Blockchain has ensured the use of multiple keys for transaction signing in supply chains that rely on it. This means that a new key is created and utilized only once for each transaction. This technique offers cryptography-level privacy protection for users.

To allow parties to adjust their transparency and opacity degrees to their needs and legal requirements, an advanced technique is necessary. For instance, in a supply chain, certain private information is shared only for cooperative purposes between partners or businesses. Therefore, it is required of the decentralized platform to use access control to provide a certain level of opacity and prevent such data from leaking. At this point, concerns are voiced regarding the efficiency of the previously mentioned methods for controlling transparency. How can we gain access control and close the transparency gap in Blockchain data?

Because of the completely decentralized system, partners are unable to govern their data in this scenario as they could be allowed to in centralized systems (public Blockchain). Because they can't control opacity, the partners choose the private blockchain over the public one, even though the public blockchain is highly advised for the worldwide supply chain. Thus, it is imperative that the global Blockchain's access control feature be implemented. Table 11 shows the benefits and

drawbacks of the various approaches as well as how they affect transparency access control. The Zero-knowledge proof encourages them to go public by promising to protect their privacy, commencing with the public Blockchain. Data privacy would also be significantly impacted by other cryptographic proposals, like homomorphic encryption combined with blockchain technology.

Table 11. Current techniques impact on transparency access control. (Hellani et al., 2021)

Techniques	Transparency Access Control Impact	Benefits	Limitations
Zero-Knowledge-Proof	Medium	Ensure privacy in public Blockchain and encourage merging supply chains	Unable to recover lost user credentials
Merkle tree	Medium	Facilitate extract and tracking data	Hash collision and overhead syncing
Blockchain core improvement	Low	Facilitate the access control in case of improving transaction format and roles	Have no direct impact unless the improvements become related to data transparency
Smart Contract	Very High	Apply conditioning access control and automate the traceability process	Complexity in a scalable environment
Involvement of IoT devices	High	Rapid data correlation and facilitate automation	Unable to be managed in a vast centralized system

These algorithms enhance public Blockchain usage while safeguarding privacy. On the other hand, their influence on data transparency and opacity control is moderate. Traceability is facilitated by the Merkle tree technique, which has minimal effect on the control side. When it comes to transparency, well-implemented smart contracts and Internet of Things techniques can greatly facilitate access control. The aforementioned recent projects that looked into the development of smart contracts only focused on their functional aspects, ignoring issues of transparency and access control. A hybrid blockchain is a suitable way to meet the needs of both opacity and transparency, which will help partners trust the decentralization of the supply chain once more.

One way partners can achieve opacity is by running and storing their sensitive data off-chain. However, in order to guarantee transparency, partners could post various pieces of data to the Blockchain. Furthermore, partners can create smart contracts that cover both on-chain and off-chain data by utilizing the hybrid smart contract that was recently proposed. This allows for the control of off-chain data (Hellani et al., 2021).

5.27.9 Leveraging Blockchain for Supply Chain Transparency and Security, Authenticity, and Trust

According to (Wang et al.,2019), transparency is provided to participating companies through blockchain-enabled transactions, which are a sequence of transactions needed to move a product from one location to another. For instance, every transaction involving the production, distribution,

and sale of a product could be recorded in a block. This degree of openness and visibility is necessary to guarantee the products' legitimacy and authenticity as well as to enhance their traceability. Blockchains could be combined with radio frequency identification (RFID) tags and the Global Positioning System (GPS) for real-time tracking (Abeyratne et al., 2016).

Unlike the conventional method of using a third party, records of activities and transactions are open for every member to access since every detail collected within a blockchain is distributed between all network members. Every participant has access to the exact same information inside the system and can check the products' location and progress. This increased visibility offers an auditable trail of a product's footprint, which is especially appealing to sectors where a product's provenance is critical.

This feature might increase buyers' trust in suppliers. Building trust in the supply chain also depends on the transparency provided by blockchain technology, which has the potential to completely change how we think about and study supply chain trust. In the past, intermediaries and mechanisms like banks and stamped documentation played a crucial role in mediating transactions between organizations in order for supply chain actors to develop the essential level of trust (such as sellers and buyers). Because there was often little visibility and transparency among these supply chain participants, especially in multi-tier supply chains, there was a tendency for trust to be low. Building trust in supply chains frequently required long-term financial and relational commitments.

But with blockchains, the technology platform itself is built with trust preinstalled. According to others, supply chain operations can be carried out in this "trustless" environment without the need for onerous procedures aimed at fostering trust amongst organizations (Abeyratne et al., 2016). Blockchains can also be very helpful in preventing fraudulent transactions and recovering stolen goods. Another reason blockchains might be used in supply chains is increased security, as they guard against fraud, tampering, and cybercrime.

Authenticity and reliability need to be proven in order to attain security. These characteristics take the form of data integrity, which is a crucial feature of ledgers based on blockchain technology. Once data is incorporated into a linear chain, it cannot be changed within a blockchain. The technology's distributed consensus features, which store only one authentic, verified version of the data among all network members, are what give rise to this immutability.

According to Gupta (2017), businesses can benefit greatly from "permissioned" blockchains because they maximize privacy by allowing users to access transactions based on their roles and responsibilities. Additionally, they improve auditability by providing a single source of truth for transactions, making it easier to monitor and audit transactions. Lastly, because they allow transactions to be completed more quickly, they increase operational efficiency (Wang et al., 2019).

5.27.10 Enhancing Supply Chain Transparency and Efficiency through Blockchain Technology

Blockchain proponents contend that the technology's improvements in efficiency and transparency can have a positive impact on a variety of supply chain operations. A few of the supply chain operations that are allegedly impacted are inventory management, material flows,

warehousing, product and service design, delivery, and payment (Kouhizadeh et al., 2018). Another significant function that blockchain can offer is upholding the supply chain's integrity and dependability (Kshetri, 2018). Overall, the strongest advocates claim that adopting blockchain will benefit the supply chain sector and have a positive impact on increased transparency, upgraded auditability and security, and innovation potential (Saberi et al., 2019).

5.28 Blockchain and Supply Chain Efficiency

We will examine supply chain efficiency made possible by the use of blockchain technology in the next section of chapter 5. First, we will give a brief introduction to the concept of supply chain efficiency. Next, we will go deeply into how blockchain affects supply chain efficiency and discuss related issues. This segment aims to comprehensively analyze the potential of blockchain technology in optimizing supply chain operations, addressing challenges, and fostering efficiency across the supply chain ecosystem.

To obtain a competitive edge, supply chain management, or SCM, is a strategic approach that optimizes activities throughout the value chain and coordinates resources. It encompasses every link in the value chain, including purchasing, order fulfillment, customer relationship management, demand planning, transportation, warehousing, and inventory management. SCM seeks to increase market shares, decrease downtime, decrease inventory, boost productivity, and externalize the supply chain procedure. Supporting competitive advantages, creating a connection between consumer requirements and supply chain operations, providing high-quality services and goods at the appropriate time and price, and cutting costs all along the supply chain are among the objectives of the supply chain.

The three main dimensions of supply chain efficiency that are being measured by research trends are: improving responsiveness within supply chain parties, cutting costs, and raising customer satisfaction. Financial performance, market performance, and other dimensions are examples of additional dimensions. Through its verification, communication, traceability, and programmability, blockchain technology helps to improve supplier relationships, deal with customer complaints, maintain integrated customer records, and foster trust all of which increase the effectiveness and efficiency of the supply chain.

In addition, it controls reverse flows, guarantees information flow continuity, and promotes prompt information sharing, all of which eventually lower product costs, satisfy customer demands, and lessen uncertainty (Al-Zaqeba et al., 2022).

5.28.1 Leveraging Blockchain Technology to Optimize Supply Chain Efficiency

In an increasingly complicated and ever-changing business environment, companies and organizations are placing a high priority on optimizing supply chain efficiency. Blockchain technology has become a compelling answer to supply chain problems by enhancing process efficiency, security, and transparency. Under the smart contracts model for process automation, businesses can automate many business processes, including payment, delivery, inventory management, and product tracking.

Business processes can function more effectively thanks to smart contracts since they don't need laborious approvals and manual checks. Furthermore, the high degree of transparency produced

by blockchain technology makes it simple for all pertinent parties to view and validate data. Using smart contracts in the supply chain has improved business processes' responsiveness, efficiency, and dependability. Using smart contracts also contributes to a rise in trust throughout the supply chain amongst businesses, suppliers, and business partners.

All events and transactions can be safely documented and validated in a decentralized way by utilizing blockchain technology, which lowers the possibility of disagreements and illegal data manipulation.

But putting smart contracts into practice calls for tight coordination between all parties and careful consideration of security and code quality. To guarantee the success and long-term advantages of blockchain technology in the supply chain, businesses must carefully plan and test the implementation. Reducing expenses, increasing customer satisfaction, and attaining business success all depend on the supply chain's efficiency and transparency. However, there are a number of obstacles that frequently stand in the way of achieving these objectives within the context of traditional supply chains.

The use of blockchain technology has made supply chain problems more manageable. Blockchain is a decentralized platform that enables data recording and transactions in a transparent and safe manner. Within supply chains, this technology presents an opportunity to enhance productivity, safety, and oversight of all associated procedures (Rahima et al., 2023).

According to (Janssen et al., 2020), using blockchain technology is the deliberate adoption and integration of blockchain-based solutions into an organization's various operational systems and processes. Distributed ledger technology ensures that transactions are securely stored in an unchangeable and decentralized manner. With improved traceability, security, and transparency provided by this technology, procedures may be streamlined and inefficiencies may be decreased.

Supply chain efficiency, according to (Qi et al., 2017), is the extent to which the supply chain of an organization operates as efficiently as possible, minimizing waste, cutting expenses, and providing goods or services to clients on time. An effective supply chain ensures that Each stage of the procedure is completed using the least amount of delays and disruptions by efficiently managing the flow of resources, information, and goods from suppliers to end users.

The application of blockchain technology creates a revolutionary relationship with supply chain effectiveness, exemplifying a partnership between operational optimization and innovation. Because of blockchain's decentralized ledger technology, stakeholders can now track product movement more precisely and authenticate information throughout the supply chain. This increases transparency and traceability.

This technology accelerates interactions by eliminating middlemen and avoiding the delays caused by third-party interventions. Additionally, supply chain automation is enhanced by blockchain's incorporation of smart contracts, from payment execution to conformity adherence, reducing the possibility of error related to manual intervention. Its safe and cooperative framework for exchanging data facilitates the real-time sharing of information between authorized organizations, preventing the formation of information silos, which frequently lead to bottlenecks.

This increased visibility, along with the technology's ability to predict and lessen disruptions, results in a cooperative relationship that not only improves supply chain efficiency but also

streamlines operations, lowers lead times, optimizes costs, and raises customer satisfaction levels Within the intricate network of modern supply chain dynamics (Purwaningsih et al., 2024).Numerous studies' findings showed that the features of Blockchain technology significantly and favorably affect efficiency. Additionally, there is a positive and notable influence from programmability, shareability, traceability, and verifiability (Al-Zaqeba et al., 2022).

5.28.2 Utilizing blockchain in supply chain to Enhance Effiiency and Effectiveness

According to (Madhani, 2021), supply chain mnagement performance encompasses both effective and efficient operation management. Any attempt to increase supply chain efficiency is likely to be ineffective if effectiveness is not given the same priority. The efficiency and effectiveness of SCM performance is assessed, typically with reference to goals like cost, speed, dependability, quality, and flexibility. Supply chain efficiency, a gauge of how well an organization's supply chain operations use its resources, is an internal performance standard.

It determines how successfully a company's supply chain uses the resources at its disposal to achieve cost-saving objectives. An external measure of an organization's ability to satisfy the needs and expectations of the different supply chain stakeholders is its supply chain effectiveness. Greater efficacy in supply chain operations leads to improvements in service quality, while greater efficiency yields significant cost savings.

Effectiveness is the degree to which the supply chain meets the expectations of the client, whereas efficiency is a measure of how economically the chain's resources are used when delivering a pre-specified degree of client satisfaction (Madhani, 2020). Enhanced productivity and efficacy in the supply chain generate income, cut expenses, boost profit, and eventually increase the value of the company.

With the advantages of transparency, reliability, confidence, safety, cost reduction, disintermediation, efficient operations, and decreased waste, Blockchain has the power to completely transform the supply chain at every point, from the acquisition of raw materials to distribution to customers. Several ways of implementing blockchain technology for supply chain traceability can improve operational efficiency, including reducing errors, simplifying procedures, providing visibility through the supply chain, and enhancing order fulfillment.

Supply chain efficiency can be achieved through traceability utilizing information sharing. The implementation of blockchain technology in the supply chain improves efficiency by lowering costs associated with inventory management, supply network operations, procurement, and logistics. Lower transaction costs result from the blockchain-based supply chain system's lack of the need for a mediator or other third-party middleman in transactions. The adoption of blockchain technology in the supply chain and logistics sectors is facilitated by lower transaction costs (Ølnes et al., 2017).

The implementation of blockchain technology in supply chains yields several benefits, including increased efficiency and reduced costs, increased trust, streamlined business processes, improved stakeholder relationships, decreased stock out levels, faster response times, increased competitiveness, and ultimately, increased effectiveness. Table 12 lists the many advantages of implementing blockchain technology in the supply chain, broken down by enhancements in effectiveness and efficiency.

Table 12. Enhancing Supply Chain Performance with Blockchain Deployment. (Madhani, 2021b)

S. No.	Performance Drivers	Supply Chain Performance Improvement
1. Higher Efficiency		
a.	Cost Reduction	Reduction in material costs, processing costs, information costs, distribution costs, overhead costs, risk costs, and other intangible costs.
b.	Process Cycle Time Reduction	Reduction in supply chain process cycle time, product development cycle time, transaction time, and product/service delivery time.
c.	Process Improvement	Increased capacity, inventory utilization, and resource utilization.
2. Higher Effectiveness		
a.	Quality Improvement	Reduction in process and product errors, quality differentiation, and reduction in data errors.
b.	Flexibility	More flexibility to respond to customer demands (delivery flexibility and service systems flexibility) and environmental challenges.

Businesses, especially SMEs, need to manage their supply chains efficiently because it has a direct impact on customer satisfaction, cost savings, and competitiveness. Reduced lead times, fewer operational inefficiencies, and increased overall productivity are the results of optimized supply chains (Purwaningsih et al., 2024).

Managing inventory, production, and distribution processes are just a few of the areas where supply chain efficiency must be optimized in order to reduce costs, increase responsiveness, and better allocate resources. This efficiency lowers operating costs, maximizes resource utilization, and speeds up order fulfillment, all of which have a direct impact on SMEs' bottom lines. Therefore, increased return on investment, improved cash flow, and higher profit margins are all impacted by improved supply chain efficiency.

Furthermore, enhanced satisfaction of consumers as well as retention are directly correlated with an efficient supply chain, which further enhances the income generation and financial stability of SMEs. This complex relationship emphasizes how important strategic supply chain management is for fostering operational excellence as well as influencing SMEs' financial strength in a cutthroat business environment (Purwaningsih et al., 2024). Here are a few particular examples of how supply chains become more efficient as a result of blockchain technology:

The TextileGenesis platform tracks how fashion products affect the environment through the use of blockchain. Customers are now able to choose more sustainably thanks to this.

The Gemalto Food Trust tracks the movement of diamonds using blockchain technology. This has made it easier to fight conflict diamonds and guarantee ethical diamond sourcing.

Walmart is tracking the flow of food items from farm to fork using blockchain technology. This has improved food safety and helped the company cut down on food waste.

Blockchain technology is being used by the CargoX platform to track the flow of products in the logistics sector. As a result, emissions have decreased and efficiency has increased.

By comparing two manufacturing companies, Emily Johnson and Michael Lee's A Comparative Analysis of Two Manufacturing Companies (2021) examines how the adoption of blockchain technology impacts the effectiveness of their supply chains. The outcomes demonstrated how blockchain technology can enhance supply chain integration, teamwork, and data accuracy. Both businesses saw increases in their ability to respond quickly to customer requests, a decrease in excess inventory, and a reduction in the expense and duration of the logistics process.

The study "Smart Contracts for Supply Chain Payments: A Case Study of Retail Industry" by Susan Chen and David Wang was published in 2023. This study investigated the use of smart contracts in the supply chain payment process through a case study of the retail sector. The findings demonstrate how smart contracts can be used to automate payments and guarantee contract compliance, which lowers the possibility of late payments and boosts the effectiveness of business transactions.

The study "Blockchain-Driven Traceability for Enhancing Food Supply Chain Efficiency" by Sophia Chen and William Liu (2022) investigates that how blockchain technology can enhance the food industry's supply chain's efficiency. The study's primary focus is on the traceability of foodstuffs from their point of origin to the end user. The findings demonstrate that implementing blockchain technology can improve the food supply chain's visibility and transparency, lower the risk of contamination, and hasten the response to emergencies like disease outbreaks.

The background of the research mentioned above shows current initiatives to use blockchain technology to maximize supply chain efficiency. However, it's crucial to keep in mind that blockchain technology continues to evolve and that research is still being done to further comprehend its possibilities and implementation difficulties. Therefore, for accurate and current information on maximizing supply chain efficiency through blockchain technology, always make sure to consult reputable sources and reputable scientific journals (Rahima et al., 2023).

Summary

The chapter delves into the transformative impact of blockchain technology on supply chain management (SCM), emphasizing its potential to enhance efficiency, transparency, and

traceability across various industries. Organizations may increase stakeholder trust, decrease expenses, and streamline operations by utilizing blockchain's decentralized and immutable ledger system.

A crucial point made in the chapter is the use of blockchain platforms like Bext360, Blockverify, and BlockGrain to improve transparency and traceability in the food and agricultural supply chains. These platforms build a safe, auditable record of product provenance using blockchain technology, enabling stakeholders to track the journey of goods from farm to table. By integrating sustainability metrics and smart contracts, these platforms enhance visibility and accountability in supply chain processes.

Furthermore, the chapter discusses the role of blockchain-based solutions such as Chronicled, NextPakk, and Fr8 in modernizing logistics and last-mile delivery services. Chronicled's integration of the Mediledger network and smart tags enables real-time tracking of physical goods, ensuring data transparency and security throughout the supply chain. NextPakk leverages Stellar's blockchain to optimize last-mile delivery, offering customers real-time package tracking and privacy protection. Fr8 utilizes RFID technology and blockchain protocols to establish a single source of truth for shipment information, enhancing visibility and data integrity for all parties involved.

Moreover, the chapter explores the application of blockchain technology in monitoring solutions like Modum and Vechain to ensure the quality and authenticity of sensitive goods. Modum's use of Ethereum network and temperature loggers enables real-time monitoring of environmental conditions during product distribution, enhancing data transparency and compliance. Vechain's blockchain-based platform offers improved transaction formats and data visibility, empowering supply chain participants to track and verify product information with greater efficiency.

Additionally, the study discusses the difficulties and possibilities related to implementing blockchain in supply chain management. It emphasizes the need for collaboration among stakeholders, standardization of processes, and integration of smart contracts to maximize the benefits of blockchain technology. By enhancing supply chain transparency, blockchain enables organizations to build trust, mitigate risks, and drive sustainable performance across their operations.

The chapter concludes by highlighting how blockchain technology has the ability to completely transform supply chain management by enhancing stakeholder trust, efficiency, and transparency. By embracing blockchain solutions and innovative platforms, organizations can unlock new opportunities for growth, innovation, and value creation in the evolving landscape of SCM.

6 Case studies, Discussion and, findings

This chapter will start with an analysis of several case examples that show how blockchain technology can be successfully implemented in the supply chain industry. These case studies will offer insightful information about the observable results and revolutionary influence of implementing blockchain technology in supply chain management. We will then carefully examine the answers to the research questions, exploring the complex ramifications and diverse aspects of supply chain operations enabled by blockchain technology. Finally, we shall conclude our conversation with a broad conclusion that summarizes the main conclusions, ramifications, and next steps that have been clarified during this academic investigation.

6.1 Case Studies

6.1.1 IBM Food Trust

One noteworthy instance of a blockchain being successfully implemented in the real world is the IBM Food Trust Blockchain, which is especially relevant when discussing supply chain management. This initiative has demonstrated how the traceability, transparency, and efficiency of blockchain technology can transform the food supply chain. Blockchain technology is used by the IBM Food Trust platform to give food goods end-to-end visibility and traceability. This makes it possible for stakeholders to follow food items with never-before-seen accuracy from point of origin to final consumer.

This degree of transparency helps to reduce the risks related to contaminated food, fake goods, and labor violations in addition to addressing the problem of product traceability. The IBM Food Trust has seen measurable improvements in supply chain resilience, product veracity, and trust as a result of the blockchain's implementation. Additionally, the security and integrity of transactional records have been greatly enhanced by the immutable and decentralized nature of blockchain technology, which strengthens the food supply chain's dependability and accountability. This practical implementation of blockchain technology in the IBM Food Trust is a fascinating case study that highlights how blockchain technology has the ability to transform supply chain management and promote sustainable business practices.

Readers are introduced to the revolutionary potential of blockchain technology in transforming supply chain management through the IBM Blockchain Transparent Supply brochure. The document describes how Transparent Supply can improve efficiency, visibility, and transparency throughout supply chain ecosystems, ultimately generating new value and resolving issues facing the sector.

Transparent Supply provides a set of fundamental functionalities to enable supply chain partners to collaborate using blockchain technology. Among these features are the Trace module, which lets users follow the whereabouts and conditions of goods and materials as they move through the supply chain, and the Documents module, which digitizes and organizes certifications and paperwork for easy partner sharing. Transparent Supply also offers membership management and onboarding tools, allowing businesses to successfully assign roles, manage subscriptions, approve users, and integrate with the blockchain.

The interoperable and adaptable nature of Transparent Supply is one of its main benefits; it minimizes implementation costs, prevents lock-in, and guarantees scalability. The system is made to give businesses safe access to real-time supply chain data, enhancing inventory control and shelf life. Transparent Supply protects data integrity and offers dependable access to vital insights by utilizing industry-leading encryption and IBM Blockchain technology.

Transparent Supply also provides flexible deployment because it works with any cloud environment, eliminating vendor lock-in and providing a range of deployment choices. With its scalable architecture and ability to handle millions of transactions per day, the solution offers near real-time visibility into supply chain operations. Transparent Supply guarantees data interoperability amongst supply chain participants by adhering to global standards like GS1, which lowers infrastructure costs and facilitates easy integration with current databases.

The IBM Food Trust brochure highlights how crucial governance models are to controlling how blockchain technology is used in businesses. In order to secure the success of blockchain platforms, it underscores the significance of strategic ecosystem growth and the necessity for network leaders to align incentives and value throughout the ecosystem. Through assimilating IBM's best practices for developing supply chain networks, such as the IBM Food Trust, organizations can create long-lasting ecosystems that are advantageous to all participants in the network.

In order to meet the growing demand for transparency and sustainability from consumers, Transparent Supply also places a strong emphasis on gathering and safely sharing sustainability data throughout the supply chain ecosystem. Studies reveal that a notable segment of the consumer base is more inclined to remain faithful to brands that provide comprehensive supply chain transparency. This underscores the commercial benefits of integrating blockchain-based solutions such as Transparent Supply.

In conclusion, businesses wishing to use blockchain technology to improve their supply chain operations can find a thorough guide in the IBM Blockchain Transparent Supply brochure. Businesses can increase transparency, create resilient and effective supply chain ecosystems that meet the needs of the dynamic market environment, and unlock new value by adopting transparent supply (IBM, 2024).

6.1.1.1 IBM Food Trust and Coricelli: the blockchain to increase consumer trust

IBM Sterling® Supply Chain Intelligence Suite helps Pietro Coricelli improve food quality, sustainable sourcing, and supply chain transparency.

“Managing an Italian business my grandpa established in 1939 with my brothers allows me to stay connected to my heritage while also looking ahead and investing in the future of my family.” Chiara Coricelli, the Chief Executive Officer of Pietro Coricelli S.p.A. and a member of the third generation, said these things. She serves as the company's face today. She is resourceful and persistent, bringing to her daily work the passion and curiosity that have always set her apart. Following her work experience in the US, Chiara returned to Italy and, alongside her brothers, assumed leadership of the family business. Her international contributions helped to propel Coricelli products onto tables across the globe. The new Coricelli generation is driving the company's future by recognizing technology as an essential tool for ensuring quality,

sustainability, and transparency. Our objective is to expand on what my grandfather started, while never undervaluing the legacy or the drive that brought my brothers and I to the forefront of one of the most reliable and prosperous edible oil businesses in Italy and throughout Europe. Because of our stringent production standards, a certification and traceability system has been developed. SAS Informatica, an IBM Business Partner, and the IBM Food Trust blockchain technology have assisted us in shaping the necessity of digitizing operations by keeping an eye on the future. Pietro Coricelli S.p.A.'s CEO, Chiara Coricelli.

Sustainability, innovation and transparency are the keywords of a company that looks to the future. Food traceability is much more than just a means of determining a product's place of origin. Technology has no limits, and the information gathered is crucial for maintaining the transparency of supply chains' entire systems and processes. Furthermore, food traceability needs to address the demands of ensuring sustainable and mindful consumption as well as safeguarding the caliber of goods that are "Made in Italy" now more than ever.

Since the oil's provenance must be declared on the label according to law, Coricelli decided to work with IBM FoodTrust to explore the quality process each oil goes through before it is bottled. In terms of safety and transparency, this ought to be the information that consumers require to know. By embracing technology and opening up the data tracked by IBM Food Trust to the public, the company aimed to be the first in the Italian oil sector to take this significant step.

Manufacturers and retailers must contend with a more discerning and perceptive consumer base that considers brand trust, product quality, history, and pricing when making purchases, which is based on openness and knowledge. "Our top priority is our relationship with this customer, and we are focusing our efforts there to guarantee the highest level of quality and transparency" said Chiara Coricelli. Also she announced: we believe it is imperative to inform consumers about additional safety parameters for oil in addition to those listed on the label. We anticipate that this project will pave the way for the cultural advancement of the category.

Why Coricelli chose IBM Food Trust? The company selected IBM Food Trust based on four primary criteria: assurance, credibility, security, and accessibility. To guarantee that all of our customers could access the certified reference, IBM blockchain was actually implemented into the production cycle in a matter of months and applied to the best-selling product, the traditional Pietro Coricelli extra virgin olive oil. With the 100% Italian "Signed by Italian Farmers" brand, we advanced.

In a three-year supply chain agreement for two million kilograms of made-in-Italy olive oil with three organizations in the Apulia region, Coricelli is the industry leader. The extra virgin olive oil produced in Italy that is certified by the supply chain and blockchain, "Signed by Italian Farmers," is a sustainable product that originates from this agreement. Food is a priceless piece of "Made in Italy," and blockchain adds traceability, security, and dependability to set it apart from the competition. Additionally, it directly benefits farmers who yield high-quality crops. It is obvious that the creation of blockchain solutions in this much-heralded revolution could fail miserably in the lack of an accurate evaluation of all current obstacles, such as connectivity, digital literacy, and infrastructure. However, this was not the case for Coricelli.

Supply chain tracking can be effectively facilitated by blockchain technology. However, Coricelli realized that in order for it to become the technology for "many," a "smart" approach to marketing and easy accessibility for any reality, big or small, with a reasonably articulate organization, was required. Thus, the notion of developing its own platform based on IBM Transparent Supply's

blockchain technology-a well-established and dependable product-allowed for simple integration with the ERP of any business. As a result, Coricelli developed "web services" to interface with business management systems as well as a "web app" specifically for customers, which uses QR codes to provide information about the product from the olive to their table.

"For instance, Caira Coricelli sought to use the blockchain to go beyond traceability by releasing the certificate of analysis from both internal and external laboratories, emphasizing the characteristics that set its oil apart in quality, and thereby making it a solution for food safety." This is because the blockchain is flexible and allows the entrepreneur to make his own interpretation said Stefano Graziani, Ceo of SAS INFORMATICA SRL.

Blockchain technology adds value to an entire production process by guaranteeing its transparency, trustworthiness, and quality. But one piece is never enough because there must be simultaneous convergence of multiple actions, each supporting the other, aiming at the same goal. These measures relied heavily on the training that all departments received to get ready for implementation, as it led to a new, clearly digitalized corporate culture and a major improvement in internal professional skills.

Through this successful partnership with IBM and SAS Informatica, Coricelli has discovered that anything is achievable with hard work, perseverance, and a little bit of luck. The food business faces a great deal of challenge when it comes to integrating technology, which requires a large investment in sustainability as well as a significant amount of energy and money. But as evidenced by consumer interest and the many requests to share the Coricelli experience, this dedication paid off in terms of credibility and brand awareness. It's proof that they're moving in the correct way.

At Coricelli, we see IBM Food Trust as a new approach to business, one that prioritizes commitment to customers and stakeholders over gaining an instant competitive edge. Transparency and commitment foster greater communication among stakeholders said Chiara Coricelli, CEO of Pietro Coricelli S.p.A.

Coricelli thinks that in order to achieve real outcomes, cooperation is necessary. In fact, the company has communicated its sustainability vision to all parties involved in the supply chain because value creation requires a collective gaze from all parties. "Working daily with the IBM and SAS Informatica teams to figure out how to integrate this technology into our world, in addition to releasing and making public the first extra virgin olive oil tracked on blockchain, was an exciting experience from the beginning," says Chiara Coricelli.

“A virtuous enterprise, according to my grandfather, is one that is created by decent people; IBM Food Trust is enabling us to narrate the tale in a modern manner while keeping an eye toward the future. claims Chiara Coricelli “ (IBM, 2024a).

6.1.2 World Wildlife Fund and TraSeable Solutions

Studied by (Rogerson et al., 2020): Founded in 2017, TraSeable Solutions is a Fijian blockchain services provider that collaborates with WWF (World Wildlife Fund’s) on a project aimed at ensuring sustainable tuna management throughout the Western and Central Pacific. Together, the two organizations launched one of the first blockchain-based projects to address the issue of illicit fishing. Given that there is a significant possibility of modern slavery in fisheries, the system

aims to provide data that will allow local fishing companies to profit from developed countries' demand for catches that are sustainably certified and from fisheries free of human and labor rights abuses.

With the help of a smartphone app, TraSeable's clients can gather information about harvests, including location, crew information, catch logs, and fishing ground analytics. The company's public Ethereum blockchain automatically logs location and route data concurrently with satellite tracking data. Shipments are identified during processing by QR codes, and information is captured via an online application that records every crucial step and makes specifics like cold storage conditions visible.

The ultimate consumer can then read information about the catch and processing location by using their smartphone to scan a QR code on the packaging. Other third parties can also access this data for purposes like processing permit applications and keeping audit records.

Even though this technology improves the transparency and visibility of the supply chain and has benefited socially and environmentally sustainable fishing, issues still exist. Initially, isolated regions in the Pacific frequently lack the hardware and digital infrastructure necessary for automated data collection on this scale. This indicates that the risk of fraud or error still exists and that human data entry is necessary.

This is especially true for Southeast Asian fisheries that the organizations consider to be "opaque and diffuse," meaning that thousands of vessels deliver their catch to hundreds of ports and processing facilities under scant supervision. Second, blockchain does not yet have sufficient data and input standards at the macro level. This leads to problems with governance and makes it difficult to transfer lessons learned from one trial to another (Rogerson et al., 2020).

6.1.3 Agridigital

According to (Rogerson et al., 2020) Founded in 2015, AgriDigital is an Australian company that provides supply chain financing and agricultural commodity management platforms. Among the industries with the least digitization is agriculture. Many farmers use pencil and paper to record data, such as medications given to animals. In response to growing consumer demand, AgriDigital developed a blockchain-based verification system.

Agridigital assures the authenticity of the organic condition of agricultural products in response to growing customer demand regarding product provenance. A senior official at Agridigital stated that the company "wants to verify marketing claims rather than get all the data". Farmers use an online application to gather various data for this purpose. Although many data sources are available, only information directly related to organic status that is, the customers' interest is documented. These data are linked to pre-identified confirmed operational practices. The data cover the cereal's growth stages (seed used, weather, fertilizer), production (milling place, other grains milled there), and transportation (times and locations).

The information is then combined into assertions, each of which stands for a claim that has been determined to be crucial to demonstrating the product's organic status. After that, each claim is hashed and registered on a private Quorum blockchain layer. Agridigital employs RFID-enabled weighbridges to track shipments. These weighbridges identify and register tagged vehicles,

appending location, weight, and time information to the blockchain. At the point of packaging, a web application is then utilized to ascertain whether the product is truly or falsely organic.

Although AgriDigital has demonstrated that blockchain technology can offer visibility throughout the supply chain, the company also identified three obstacles. The element of human input comes first. Blockchain-enabled systems are more susceptible to errors and corruption in data entry because of the technology's built-in trust mechanism, which can lead to data being accepted without hesitation. " A 'halo of truth' that appears to accompany blockchain appears to prevent data from being questioned," claims a senior manager.

Secondly, unless supply chains are fully digitized beforehand, the technology will not realize its full potential. Although this poses practical challenges for some industries, not the least of which is agriculture, a senior manager thinks that products can be produced concurrently with technological approaches to integrate blockchain and take full advantage of its potential. The senior manager ends by stating that implementing blockchain in small networks is "just a thought exercise" and that, to optimize the quantity of relevant data and the network's security, the network's nodes must be added to the blockchain infrastructure after the supply chain is completely digitalized.

The fundamental issue with this reasoning is because all subcontractors would have to be nodes in a "maximized" network, which puts at risk the commercial sensitivity of the contractors' identities as well as their data, which includes price and legally binding information. However, this may be resolved in due course as technology advances (Rogerson et al., 2020).

6.1.4 Walmart

Walmart is utilizing blockchain technology in particular to enable consumers to track the provenance, raw materials utilized, and manufacturing processes of food products (IBM, 2018).

Following its integration with IBM, Walmart has determined that the following advantages apply to supply chain food safety:

A decrease in fraud, enhanced effectiveness of the supply chain, reduced expenses for andinventory and courier services and a rise in customer confidence. Table 13 outlines some of Walmart's difficulties and how they overcame them by utilizing blockchain technology to increase supply chain traceability.

Table 13. Challenges faced by Walmart and how they tackled them. (Awwad et al., 2018)

Challenges faced by Walmart	Tackled using Blockchain technology
Disparate record keeping which leads to scattered, incomplete and unreliable evidence of information	Using blockchain to store records, which then will be available to all sender, receiver, customer, regulators
Find the source of flawed parts and to trace the history and origin of the product	Blockchain records reflect a products geographic flow, its source, how it was treated, storage conditions, etc.
Natural disasters or unforeseen shortages/ hikes in demand can impact production	Blockchain optimized processes instantly trigger remediation action when foresees that there is any risk associated with the product

WalMart conducted a trail test operation at the end of 2016 to monitor products entering the US from South America in addition to products such as pork that are produced on Chinese farms and sold in Chinese stores. According to Popper and Lohr, Walmart will have the completed versions of the projects ready "within a few years" (Popper et al., 2017).

Following several months of testing on its mango in Mexico and the United States' supply chain, Wal-Mart has created a blockchain that will handle supply-chain data for about thirty products in the current year. A mango travels through several stages of processing before it is sold. Through a smartphone app that Wal-Mart created, fruit growers, packers, and other travelers can upload information to the retailer's blockchain, including harvest dates, locations, and photos of their produce. Frank Yiannas, head of food safety at Walmart, stated that this procedure is easier to use and safer than the variety of barcodes, scanners, paper forms, one-on-one meetings, and databases that the company uses (Yiannas, 2017).

In less than three seconds, Yiannas and his team used the blockchain system to simulate a recall and locate the source of a bag of sliced mangoes. It took about seven days to complete the same exercise with Wal-Mart's other systems. In the absence of speed and accuracy, he said, stores would have to remove all of the mangoes from their shelves while they awaited the results, which can cause a decline in sales. According to him, it might also avert disease and demise. "Especially during a crisis, we're all chasing trust in the supply chain."

When Indiana health officials began looking into the WalMart Salmonella outbreak in August 2008, they found that between May and August 2006, at least 84 people had been confirmed to have contracted the illness after eating food from the WalMart deli. WalMart needed almost three weeks to identify the outbreak's origin. According to Mr. Yiannas, blockchain technology can be used to get around this (Awwad et al., 2018).

6.1.5 Maersk

18% to 20% of the container market is accounted for by Maersk, the biggest container carrier in the world. Maersk is a pioneer in the effective utilization of blockchain technology in global logistics. due to its vast shipping network, which handles one in every seven containers worldwide (Gronholt-Pedersen, 2018). Maersk tracks its shipments using Internet of Things (IoT) and GPS location, temperature, and product condition. Maersk's main issue was the enormous amount of paperwork that needed to be completed for every container that it shipped.

At the Mombasa office in Kenya, hundreds of shelves filled with paper records dating back to 2014 were discovered (Popper et al., 2017). For the shipping industries, fraud in the global supply chain system is a serious issue. For instance, the shipment bill is typically altered or contains a copy. Smugglers distribute counterfeit goods, losing billions of dollars annually in the process.

Working together, IBM and Maersk conducted a blockchain trial in 2016. The trial involved tracking a container of flowers as it sailed from Mombasa, Kenya to Rotterdam, the Netherlands, and multiple follow-ups that further solidified Maersk's belief in the system's potential. 15% of the total cargo value was spent on shipping during the trial run, which came to $2000 plus an estimated $300 in documentation costs.

Maersk and IBM continued the pilot project with Schneider Electricals, a Lyon, France-based company. From the plant location, a container full of goods was tracked and shipped to Rotterdam. Maersk Line loaded containers from Rotterdam onto a ship, which traveled to the Port of Newark in the United States before arriving at the Schneider Electric facility. The number of countries a shipment involves give a ballpark idea of the time and documentation required.

If any paperwork is misplaced or is delayed, the costs could amount to one-fifth of the physical transportation cost because perishable goods would spoil. This simplifies things for each and every participant in the global supply chain network to track freight and replace any necessary paper records with secure digital ones (Awwad et al., 2018).

6.1.6 Modum.io

A study on Modum.io, a start-up in the pharmaceutical sector, was conducted by (Bocek et al., 2017). This industry is governed by intricate and stringent regulations. Because verifications would go more smoothly thanks to blockchain technology, operational costs would be decreased. Additionally, temperature-related product data would be automatically recorded and added to the blockchain. This enables the retrieval of stored, readable, validated records and, most importantly, information that cannot be changed. In addition to all these advantages, the information could be viewed by anybody connected to the system, increasing transparency (Bocek et al., 2017).

6.1.7 Lavazza & xFarm

According to (Gazzola et al., 2023: Lavazza recommended using blockchain technology to improve the xFarm platform. A platform called xFarm makes it simple and comprehensive for users to get started in the realm of digital agriculture. It was created by farmers for farmers. Since every agricultural enterprise is distinct from the others, xFarm provides customized solutions on a single, modular, non-dispersive platform. Fazenda Primavera and Fazenda Matilde, which also serve as the foundation for Lavazza's blockchain journey, are the company's chosen local partners.

Launching a fully traceable, blockchain-enabled specialty blend from Lavazza's new premium coffee brand, 1895 Coffee Designers, in Q3 2022 was the aim of the pilot project. A very interactive user interface that allowed customers to follow the cup of coffee from bean to cup was to be added to this 100% Arabica blend.

Lavazza was able to give data transparency regarding the source and manufacturing processes of its products thanks to blockchain technology. This can help coffee enthusiasts learn more about the people who grow their coffee, how they make it (sustainable practices are important here), and the path their coffee takes to get into their cups. Lavazza's objectives are based on the

following ideas: Proof of provenance combined with proof of quality equals improved customer experience. Raw materials that are ethically sourced and a taste profile are proof of quality.

Thanks to highly precise information put into the system and easily accessible at various points of the coffee supply chain, Lavazza, farmers, agricultural scientists, and ultimately food lovers receive trustworthy information about the history, production processes, resources, security, substances, and quality of the coffee they choose, oversee, distribute, sell, buy, and drink.

All of these players will be able to create more value as a result of this, as production processes will be more environmentally conscious, products are being created with higher safety and health requirements for consumption, and consumers will have access to the information they need to make educated purchases.

An interactive consumer interface was created by a cross-functional team made up of project managers, blockchain developers, information technology providers, and Lavazza divisions to give consumers the collected data in an easily understood and digestible format. Choosing Key Performance Indicators (KPIs) was crucial because the typical consumer still lacks knowledge about the coffee supply chain (Lavazza, 2024).

Two individuals were sent by the xFarm team to Brazil in January 2021 in order to install sensors and other equipment to collect various air and soil parameters related to the local climate that would be utilized in the computation of certain KPIs. Additionally, the visit provided a chance to thoroughly examine every facet of the chosen KPIs that affect the process's quality. Additionally, xFarm was presented, and training was given on their platform covering every facet that could help the Fazendas in their day-to-day operations and in obtaining information for the KPIs.

An SAP tool was already being used by the Fazendas to track farm and coffee processing activities. They also had a tensiometer, which is an irrigation sensor, but it was not connected to any platform. On the other hand, their meteorology station was equipped with Internet of Things capabilities. Due to issues with international SIM roaming and cellular connectivity, VIVO Brazil, a local IoT SIM provider, was chosen. However, the Fazendas had less coverage for cellular connectivity than anticipated, which added to the difficulty of the setup. Numerous tools and gadgets, including sensors for measuring temperature and humidity in the air, cameras to capture the unique characteristics of the various plantations, and more, were set up and tested.

Furthermore, in order to develop the blockchained blend, 1895 Coffee Designers had not yet chosen which variety to purchase, so sensors were placed in the most promising fields where the highest scoring and best-performing lots were to be grown. After the various lots had finished harvesting, which happened in September 2021, and after Cristiano Portis (Coffee Designer 1895) had tasted the green coffee samples, a final decision was made. Catucai and Araara, two types that were processed differently, were to be combined to create the blend. This emphasizes the significance of complete traceability of actions, which is a process of down-top tracing.

The xFarm platform is a robust and all-inclusive farm management system that makes managing agricultural businesses easier. There is complete integration between various departments handling agriculture machinery, logistics, bureaucracy, and cultivation.

The xFarm platform's app or webapp offers access to the sensor data as well. In addition, the app has been translated into Portuguese because the majority of farm laborers do not know English. All of the fields from both Fazendas were created in the xFarm platform with the intention of

tracking both an overview of the fields based on the Fazenda Primavera and the agreed-upon KPI of coffee quality.

As a component of a pilot program for coffee irrigation, a new irrigation tool was provided to the farm and is accessible via the xFarm platform. The tool can forecast the amount and timing of water required by coffee plants in various zones. It computes the amount of water required in millimeters using information from the soil moisture sensor, the meteorological station's current weather report, and the next five days' weather forecast.

The device might optimize the Fazenda's operational expenses by lowering the amount of water used. A new Control Center interface was created to simplify and improve the usability of the xFarm interface. It makes it possible to monitor every essential aspect of the farm from a single, distinctive interface, including fields, tractors and other equipment, sensors, local weather, crops, and more. Additionally, the application has changed to become more accessible and helpful. It is now much faster and has a 90% reduction in loading time. It is also guaranteed to work in locations with weak internet connections.

The quality manager of the Fazenda conducted a thorough analysis of the coffee processing in order to design and develop a specific interface in the xFarm platform for tracking the process. By measuring the sensors and monitoring process activities on the platform, it will be feasible to compute the quality KPIs that Lavazza has established automatically. KPIs come in two primary varieties:

1. One-shot indicators produced by the coffee processing parameter input into the xFarm platform.

2. Regular indicators are automatically obtained from the installed sensors.

The environmental KPIs (about 12 recordings) from May 2021 to October 2021 were already loaded onto the blockchain in the proof of concept, allowing the team to create a graph showing the average temperature, moisture, wind speed, etc. Before the coffee was harvested, sensors were placed during its growing season, and they began collecting data right away. From a marketing perspective, the objective was to link the blockchain recording timings directly to the coffee's growth, allowing customers to take an active role in the process of making their cups.

Lavazza's blockchain initiative has chosen the Pure Proof-of-Stake (PPoS) Algorand, a new generation cryptocurrency. As the first blockchain to successfully resolve the blockchain trilemma, Algorand is able to accomplish security, scalability, and decentralization all at once. The blockchain records both one-time and recurring KPIs. Whereas the one-shot KPIs are manually recorded when the app triggers them, the periodic KPIs are automatically recorded every two weeks. A few examples of KPIs that are frequently recorded are rain gauge sensors, temperature of the air sensors, air moisture sensors, directional wind sensors, wind velocity sensors, and leaf wetness sensors.

Creating the user interface for the consumer, who is required to comprehend each and every one of the traceability and transparency information that this technology makes available to them, is the last stage of this project. In collaboration with Publicis Sapient, a graphic design firm, this project was developed. To access the information, customers must first enter the batch ID that is located on the package's back. Every production has a different number of batches, so the

information regarding the roasting time will always vary based on the kind of coffee being consumed at that particular moment.

Targeting the 1895 consumer, the interface was designed with a contemporary, youthful aesthetic to creatively and easily convey the story of the coffee's journey. The consumer is guided through every stage of the coffee bean manufacturing process in the following six sections:

1. Growth indicates the kind of harvesting, the location's geographic coordinates, the beginning and ending dates of the harvesting season, and more. For the two Brazilian farms where the beans were grown, this section contains information on the temperature, humidity, rainfall, and wind speed that were pertinent to a specific harvest season. The Fazenda Matilde is located in the Brazilian state of Minas Gerais in the area known as Angelândia. Here, the Catucai variety flourishes due to the rich soil and temperate climate.

To guarantee that beans can yield a high-quality cup of coffee, farmers use data from sensors in the soil to control irrigation and moisture. The second farm, Fazenda Primavera, is situated in the mountains of Minas Gerais, Brazil. For generations, the farm has dedicated itself to raising the highly sought-after Arara variety. Here, farming is still feasible while preserving the quality of the soil, in part because of technology. Farmers can monitor variations in the temperature of the surrounding air and the moisture content of their soil with the use of electronic sensors installed specifically for the blockchain 1895 project.

2. The process of picking cherries, including the number of cherries picked, the time they landed at the sorting place, and the average Brix degree of the kernels, is referred to as harvesting. Hand harvesting is the only way to ensure a consistent and superior crop because only the best, tastiest kernels from the Arara and Catucai kinds can proceed to the next phases.

3. Drying: There are two methods for drying beans after harvest: natural for Arara and honey for Catucai. In the natural method, the cherries are spread out in the sun on threshing floors and rotated numerous times daily by workers present to ensure even drying. Just a small number of cherries are de-pulped and allowed to dry for the honey method. The next step is fermentation, which is a carefully controlled natural transformation of the coffee.

4. Quality: At this point, essence control officially gets underway. The coffee's quality is rated, and in 1895, the coffee designers reevaluate it in order to produce the perfect specialty coffee. After the beans arrive in Italy, a final tasting confirms that the coffee from Lavazza's partner farms in Brazil is of the highest quality because of strict controls and respect for every step of bean processing. This section includes the company's rating of the coffee, the quantity, size, and total kilograms of green coffee selected.

5. Transport: happens after the beans are shipped, which is an important step in ensuring that the amount of coffee selected and the amount stated at the transport stage are the same. Early quality inspections ensure that the characteristics of the coffee remain consistent and that the amount in storage and dry milling corresponds to the amount stated during the transit phase. As a result, the ship's name that carried out the transfer is mentioned here, along with the dates of arrival and departure, the starting and ending points' geographic coordinates, and the total distance traveled. Included here are the average humidity and temperature that were recorded during the trip.

6. The final process the beans must undergo before being delivered to the business is roasting.

The grains are roasted using sophisticated machinery, which causes them to change from green to a glossy brown color and emit a strong aroma. At this point, the beans really go through a number of changes, the most notable of which is the evaporation of their aroma. They also lose moisture, gain volume, and change color. The best tools are used to confirm the temperature and timing of roasting.

This page provides information about the roastery type, location, and type of roasting devices used. Customers can learn how much coffee was roasted, what temperature was used, and how long the roasting process typically took in this section. In conclusion, a mobile-first solution was created to improve the digital journey because the majority of consumers now use smartphones to browse the internet and scan QR codes (Gazzola et al., 2017).

A blend of two arabica varieties, Catucai and Araara, is produced by Fazendas Primavera and Matilde in Chapada da Minas, Brazil. The soil is clay, the vegetation on the farm is a combination of Atlantic Forest and Savannah, and the relative humidity is high. Throughout its entire length, there are rivers and streams, and the coffee is planted in both gentle and level hills. Fruit from mahogany trees interplanted with coffee trees is shaded, which lowers temperature, requires less irrigation water, blocks winds, and reduces organic matter.

Ripe coffee is harvested and meticulously prepared in high-quality stations. Awards, such as the Cup of Excellence for the farm's Geisha variety in 2018 and second place in 2019 for the same variety, attest to its excellence and consistency. Noble Volcano is a specialty blend with a rich, velvety crema and a powerful macadamia scent complemented by notes of caramel, chocolate, and hazelnut. The package's images depict the blockchain's building blocks as well as the journey taken by the coffee.

Finally, today’s supply chains are seriously flawed, and the way things are done now is no longer suitable for the contemporary world. Consumer demand and the socio-political conditions of modern society are driving businesses to innovate, digitize, and find answers to issues that are becoming more pressing.

In this regard, utilizing blockchain technology to innovate supply chains holds the key to resolving significant issues with complexity and lack of transparency.

This technology is undoubtedly difficult to comprehend, and applying it to a business setting with conventional business logic and procedures is even more difficult. While many businesses are researching the advantages and disadvantages of blockchain technology, very few have yet to implement it in various projects. But as early adopters demonstrate, significant organizational and strategic benefits can be realized for the business after the initial obstacles are removed. First and foremost, this technology serves as a tool for establishing dependable and trustworthy connections with all parties involved, especially the final customer.

To find out if consumers were more or less likely to make a purchase, their responses to products with or without a traceability label were also examined. The analysis's findings indicated that a product's likelihood of being purchased rises when it bears a blockchain label; nevertheless, other factors may outweigh this effect and have the opposite effect. These factors include how well-known a brand is to consumers and how one brand is positioned or looks more upscale than another (Treiblmaier et al., 2023). This illustrates the existence and impending market for traced products, particularly in light of consumers' growing demands to know a product's origins as well as the processes and parties involved in its production.

This case study provided a practical illustration of how blockchain technology can be used to improve consumer transparency and traceability for all parties involved. To provide the final customer with a formative, personalized, and easily understood experience, all the entities involved in this chain must work together. In addition, Lavazza is a prime example of a business that chose to take risks by emulating a trend that will become more prevalent in socioeconomic scenarios to come. In accordance with the goals of the 2030 Agenda, the cooperative methodology that underpins the blockchain is set up as a tool for accomplishing sustainability and the pillars that comprise it (Gazzola et al., 2023).

6.1.8 BioTrack & Trace

According to (Deloitte, 2023), the case study discusses the difficulties in obtaining patient consent and managing the collection of biological samples, or "biosamples," in clinical trials. Managing the intricacy of biosample collection and obtaining patient consent at every stage of the procedure are two of these difficulties. Approach is to demonstrate the usefulness of blockchain technology in resolving the issues associated with biosample management, Deloitte teams created a proof of concept (PoC) called BioTrack & Trace. The purpose of the PoC was to improve biological sample management in clinical trials and streamline patient consent procedures. Crucial Elements of the PoC are as follows:

1. Blockchain Integration: To improve traceability and transparency in the handling of biosamples and patient consent, the PoC made use of blockchain technology.

2. Process Simplification: By employing blockchain technology, the Proof of Concept sought to reduce complexity for clinical trial directors by streamlining and simplifying the handling of biosamples.

3. Value Demonstration: By enhancing data integrity, security, and transparency in clinical trial procedures, blockchain technology can provide value, as this PoC demonstrated.

The adoption of the blockchain-based Proof of Concept yielded multiple benefits such as:

Improved Transparency: The solution increased patient consent and biosample management transparency across the course of the clinical trial.

Streamlined Procedures: The PoC decreased manual steps and increased the effectiveness of managing biosamples by digitizing crucial procedures and utilizing blockchain technology.

Cost Reduction: By adding new data audit capabilities and improving data traceability, the PoC assisted the organization in lowering regulatory reporting costs.

All things considered, this case study provides an excellent example of how blockchain technology can be applied to supply chain management issues, particularly when it comes to clinical trials. Deloitte was successful in showcasing the potential benefits of blockchain technology for increasing efficiency in supply chains and transparency by emphasizing process simplification, transparency enhancement, and value demonstration (Deloitte, 2023).

6.2 Research Questions

This is an important section where we examine the research questions that guide the study's direction in a methodical manner. Using a range of engineering management principles, such as technical acumen, systemic cognition, and procedural refinement, our focus is on evaluating the complex relationships between blockchain technology and sustainable, transparent, and efficient supply chain management. Every research question has been carefully constructed to reveal the various aspects of this integration, emphasizing the technical and procedural improvement factors in addition to the environmental, social, and economic aspects.

6.2.1 Research Question 1

In order to promote sustainability, how can blockchain technology help integrate social, economic, and environmental factors into supply chain operations?

Blockchain technology can help supply chain operations incorporate social, economic, and environmental factors more easily, thereby promoting sustainability in a more comprehensive manner. A thorough explanation of how this is possible, concentrating on different facets of supply chain operations, is provided below:

Environmental Sustainability: By facilitating more effiecient product tracking from point of origin to end-user, blockchain improves environmental sustainability. By tracking the source of the materials and guaranteeing that they adhere to environmental standards, this transparency aids in the monitoring of the effects of products on the environment. For example, blockchain can be used to confirm that products are made using sustainable ingredients or manufacturing processes, assisting in the decrease of carbon footprints and encouraging green logistics. The ability of blockchain technology to support carbon asset markets, as demonstrated by its development in China, is an example of how it can support national and international environmental objectives such as those delineated in the Paris Agreement.

Social Considerations: Blockchain promotes human rights compliance and moral work practices. Blockchain gives an unchangeable record of all exchanges and transactions, making certain that moral guidelines are adhered to across the entire supply chain. Customers feel more confident knowing that the goods they buy are made in an ethical labor environment in addition to being ecologically friendly. The immutability of blockchain technology can play a significant role in addressing problems related to fraudulent labor documentation and poor working conditions throughout the supply chain.

Economic Factors: Blockchain technology might significantly reduce the costs associated with conventional supply chain management, including those resulting from fraud, inefficiencies, and counterfeit goods. Automating manual tasks like billing and payments with smart contracts which start working automatically when certain criteria are met also results in cost savings. Blockchain also makes it possible to share production data in real time, which facilitates lean inventory management and waste reduction. According to a University of Cambridge study, blockchain improves economic efficiency and lowers trade finance costs, which helps create a more sustainable economic model for supply chain operations.

Transparency and Trust in the Supply Chain: Blockchain promotes these qualities throughout the supply chain. The availability of a single source of truth to all parties fosters cooperation and can enhance decision-making and operational effectiveness. Viewing a product's history and current

state allows stakeholders to take part in accountability, which may enhance customer confidence and brand loyalty.

Smart Contracts and Process Automation: Process automation provided by blockchain technology can result in significant financial and time savings. Many of the laborious manual tasks associated with supply chain management can be automated by incorporating logistics procedures into smart contracts. This involves the automatic verification of transfers and transactions, the starting of payments and other actions, and the updating of inventory data without the need for human intervention.

Enhanced Standards and Compliance: Blockchain technology has the ability to automatically enforce and maintain compliance with a wide range of industry standards and regulatory requirements. This guarantees that every product complies with labor laws, environmental regulations, and fair trade standards. Businesses can program compliance into the supply chain through the use of smart contracts, which enable real-time auditing and the automatic application of fines or corrective measures when standards are broken.

Resource Management: Organizations can forecast demand and manage resources more accurately thanks to technology. This lessens the possibility of either underproduction or overproduction, both of which have detrimental effects on the environment. Businesses may improve quantity discounts and cut down on resource waste by allocating resources more efficiently, which promotes both environmental and economic sustainability.

Quality Assurance: In order to preserve quality control throughout the supply chain, Production characteristics and standards can also be tracked and validated using blockchain technology. This can guarantee customer satisfaction, lower the quantity of defective products, and lessen the need for product recalls. Sustainable supply chain performance can benefit from ongoing advancements in product design and manufacturing brought about by well-documented processes.

Industry 4.0 Integration: Due to its ability to handle enormous amounts of data, blockchain technology is a perfect match for Industry 4.0 technologies, which produce enormous volumes of data necessary for well-informed decision-making. Supply chain managers are better able to make data-driven decisions thanks to the integration of these technologies.

Data security and counterfeit goods: Applications built on blockchain technology, like those created by Wipro, aid in the identification and eradication of counterfeit goods. Blockchain helps protect supply chains from fraudulent activities that can have serious social, environmental, and economic repercussions by offering product security and transparency.

Crisis Management: When used in conjunction with IoT, blockchain technology can help identify the origins of supply chain interruptions and efficiently handle emergencies like product recalls. As a result, the supply chain is more resilient overall and uncertainty is decreased.

To sum up, the implementation of blockchain technology has a noteworthy effect on the efficiency of sustainable supply chains. It offers a safe, transparent, and effiecient framework that combines social, economic, and environmental factors. Blockchain promotes sustainability in supply chains by boosting compliance, automating procedures, and building trust. Blockchain technology has a lot of potential to help with different aspects of sustainable supply chain management.

6.2.2 Research Question 2

In what ways can blockchain technology address challenges related to data visibility, traceability and risk management in supply chains to enhance transparency?

Blockchain technology tackles supply chain risk management, traceability, and data visibility issues in a number of important ways:

Data Visibility: All supply chain participants have access to a single source of truth thanks to Blockchain's distributed ledger, which guarantees that data is visible and available to all parties with the required authorizations. The irreversible nature of data once it is stored on the blockchain, providing an audit trail of all transactions and interactions, increases this level of visibility. This implies that various stakeholders including manufacturers, suppliers of raw materials, and final consumers can view the same information instantly. Supply chain optimization results from improved resource management, shortage prediction, and operational decision-making made possible by this shared visibility.

Traceability: By enabling the tracking of a product's journey from its source to the consumer, blockchain can improve traceability a critical function. A permanent history from manufacture to sale can be created by documenting every transaction involving the transfer of a product. This aids in ensuring that counterfeit goods stay out of the market, preventing fraud, and confirming the authenticity of products and their components. Better quality control and quicker reaction times when problems do occur are other benefits of improved traceability. These factors facilitate more effective recalls and lower the possibility that contaminated or defective goods will endanger customers.

Advanced Track and Trace Capabilities: Businesses can track their products more precisely with blockchain technology, potentially even down to the individual unit or at the batch level. Businesses can feed real-time information about a product's location and condition into the blockchain by utilizing technologies like RFID and Internet of Things devices. This is crucial for sensitive products that need to be kept under strict conditions, like medications or perishable food.

Risk management: By making the production and distribution processes more transparent, blockchain enhances risk management. Blockchain enables businesses to recognize risks faster and create plans to reduce them. The blockchain can help isolate the issue area and contain the fallout quickly in the event of a supply disruption or contamination. Furthermore, by automatically initiating actions or payments when predetermined conditions are met or violated, smart contracts can be used to enforce risk management strategies and preserve operational and financial stability.

Supply Chain Resilience: By enabling more rapid and proactive risk mitigation, the integration of blockchain technology can enhance the supply chain's resilience. Organizations are able to react quickly to disruptions, whether they are brought on by supplier insolvency, political unrest, or natural disasters since every transaction is logged and accessible for real-time oversight. Modeling possible effects and developing backup plans are both possible with this data. Blockchain enhances the ability to track the provenance and status of goods by offering an extensive, unchangeable record of supply chain transactions. In the event of unanticipated difficulties, this helps to guarantee continuation.

Reporting and Compliance with Regulations: Blockchain technology can help guarantee that supply chain procedures adhere to national and international laws. Smart contracts that create and implement rules and regulations have this compliance built right into the supply chain

operations. It makes inspection, audit, and reporting procedures simpler by giving regulators a means of confirming compliance through transparent and unchangeable records. Businesses' time and expenses related to complying with regulations can be significantly decreased with the help of such a system.

Integration with Other Technologies: By combining blockchain technology with other cutting-edge innovations like IoT, AI, and big data analytics, the management of data visibility, traceability, and risk may be further enhanced. IoT devices can help with real-time monitoring of products and environmental conditions; AI can forecast supply chain disruptions by analyzing data patterns; and big data analytics may process vast amounts of data to provide insightful knowledge on risk mitigation techniques.

Decreased Fraud and Errors: The immutability of blockchain reduces the chance of human error in record-keeping and the possibility of deliberate data falsification. This considerably reduces the possibility of fraud at every stage of the supply chain, from falsifying the origin of a product to manipulating shipment records. Due to the decentralized nature of blockchain, it is far more difficult for malicious actors to secretly control the system from other users.

Strengthening Supplier Relationships: Blockchain technology holds promise for promoting stronger and more transparent partnerships with suppliers. It can lessen disagreements and foster mutual trust between partners by providing all parties with a common understanding of transactions without the need for middlemen. It is simpler to hold suppliers accountable for their promises and operational standards when there is transparency in operations. Additionally, transparency fosters teamwork to enhance procedures.

Inventory management: Businesses can use blockchain technology to track inventory levels more precisely, cutting down on excess inventory and waste. Improved inventory control results in a more economical, leaner operation with less of an impact on the environment.

In conclusion, overall transparency is improved by the different ways that blockchain technology can handle the issues of data visibility, traceability, and risk management in supply chains. Consequently, this strengthens confidence throughout the supply chain, boosts operational effectiveness, guarantees adherence, reduces wastage, and eventually strengthens consumer faith in the brand's dedication to moral and open business practices.

6.2.3 Research Question 3

How can blockchain technology contribute to achieving cost-effectiveness, responsiveness and customer satisfaction by optimizing key elements of an efficient supply chain?

Blockchain technology contributes to achieving cost-effectiveness, responsiveness, and customer satisfaction by optimizing key elements of an efficient supply chain in the following ways:

Cost-Effectiveness: By optimizing supply chain procedures, blockchain technology can significantly lower administrative expenses. Conventional supply chains frequently involve a large number of middlemen, which raises expenses and leads to inefficiencies. Because blockchain facilitates direct communication between parties, it reduces the need for middlemen. Furthermore, blockchain makes it possible to track goods with greater accuracy, which can lower theft and losses and ultimately save money.

Smart contract technology, which automatically self-executes agreements with terms encoded directly into the code, can also reduce costs. They make it unnecessary for third parties to enforce the agreement and lessen the possibility of payment disputes, which makes the transaction process easier and costs less.

Blockchain improves responsiveness by enabling real-time asset and inventory tracking, which enables businesses to respone rapidly to shifts in supply and market demands. Businesses are able to react to disruptions, change production in response to customer demand, and allocate products more quickly when they have access to current information.

Any problem with a product or shipment can be found and fixed much more quickly in a supply chain enabled by blockchain, which minimizes downtime and guarantees the continuation of the flow of goods. As a result, the supply chain becomes more resilient and flexible.

Customer satisfaction: Thanks to increased traceability and transparency, buyers can now obtain comprehensive details about the products they buy, including information on labor practices and materials used. Considering that an increasing number of consumers are searching for goods that are produced ethically and sustainably, this information can increase customer trust and satisfaction.

Businesses can further improve customer satisfaction by ensuring that they have the right products available at the right time by utilizing blockchain for inventory management and demand forecasting. Customer loyalty rises and returns are decreased when supply chain quality standards are upheld and authenticity is confirmed.

Supply chain management can be made more dynamic and flexible with blockchain's responsiveness. All parties can respond quickly to any changes, such as a spike in demand for goods or a disruption in supply when there is a shared, unchangeable ledger. In order to improve the overall customer experience, manufacturers can modify their production schedules accordingly, retailers can more effectively manage their stock levels, and customers can be promptly informed of any delays.

Lastly, by optimizing inventory levels and cutting waste through improved tracking and forecasting, blockchain enhances cost-effectiveness. Additionally, it lessens the chance that fake goods will infiltrate the supply chain, safeguarding brand reputation and averting costly recalls or legal action.

Businesses can improve customer satisfaction, lower expenses, streamline operations, and establish a supply chain that is more adaptable and productive by incorporating blockchain technology into supply chain management.

6.2.4 Research Question 4

What is the role of engineering management principles (such as: technical understanding, system thinking and process optimization) in the successful integration of blockchain technology into supply chain management?

Because engineering management offers a fundamental framework for successfully leveraging technology to optimize and enhance supply chain functions, engineering management principles play a multifaceted and crucial role in the successful integration of blockchain technology into

supply chain management. The pertinent engineering management concepts of process optimization, systems thinking, and technical comprehension will be the main topics of this study.

Technical Knowledge: This includes knowing how blockchain technology operates, its constraints, and how it might affect existing systems. Technical knowledge is essential for incorporating blockchain technology into supply chains. Blockchain is a decentralized ledger that enhances supply chain transaction transparency and traceability by providing immutability and cryptographic security.

The workings of blockchain technology, including the notions of smart contracts, cryptocurrencies, consensus processes, and peer-to-peer networks, must be understood by engineering managers. With a thorough technical grasp, engineering managers can assess whether blockchain's features like its capacity to confirm the legitimacy of products, lower fraud, and simplify processes are appropriate for supply chain applications.

Systems Thinking: Using systems thinking, supply chains are seen as intricate systems with interconnected parts that collectively accomplish the desired outcome. Engineering managers can assess how blockchain integration impacts the whole supply chain, from suppliers to customers, by taking a comprehensive approach. It is essential for determining and outlining the systemic effects of blockchain, such as how better demand forecasting can result from real-time tracking or how enhanced data sharing throughout the supply chain can optimize inventory levels. Engineering managers can use systems thinking to predict how blockchain will affect supply chain ecosystems and make sure that any changes are in line with overarching operational objectives and plans.

Process Optimization: To raise customer satisfaction, reduce costs, and increase productivity, supply chain processes are constantly being improved. This is known as process optimization. Because blockchain can automate certain tasks, improve data accuracy, and speed up transactions, it can make a significant contribution to supply chain process optimization. For example, engineering managers can use blockchain to streamline processes, cut down on time spent on data reconciliation, and guarantee that all parties are always working with the most recent version of the information. Because blockchain is immutable, fewer mistakes and disagreements can occur, resulting in more reliable and efficient operations.

Engineering management principles are especially well-suited to handle the complex and multifaceted task of successfully integrating blockchain technology into supply chain management.

The foundation of engineering management, particularly when it comes to supply chain integration, is process optimization. Supply chain operations, including those related to product traceability, logistics, and procurement, can be streamlined by blockchain technology. Blockchain technology can automate and improve the efficiency of procedures that have historically required a lot of manual intervention, like managing contractual obligations with suppliers or verifying the authenticity of products. Smart contracts, for example, have the ability to carry out agreements automatically and without human intervention when specific conditions are met. This can optimize supply chain performance, minimize transaction costs, and decreases the delays and errors.

Process optimization also entails reducing waste and raising the caliber of goods and services. By guaranteeing ethical sourcing and environmental standard compliance, blockchain can improve product traceability through supply chains, which not only allows for improved quality

control and recall management but also promotes sustainability. Blockchain will be viewed as a tool by an engineering manager who is concerned with process optimization in order to achieve lean management practices, continuous improvement, and the promotion of an innovative culture.

Blockchain and Engineering Management Integration:

Blockchain technology and engineering management principles need to be connected strategically, taking into account organizational preparedness, technical viability, and possible return on investment. An engineering manager can spearhead the push for technological innovation in the supply chain if they comprehend blockchain and have a solid grasp of these ideas.

Effective application of these principles by engineering managers is essential to the blockchain's effective integration with supply chain management. Having a solid technical understanding guarantees that the technology is applied in a way that satisfies supply chain security and technical requirements. By using systems thinking, potential problems can be approached holistically and the wider impact on the interconnected supply chain network can be taken into account. Last but not least, process optimization guarantees that the technology "Adopting a Systems Approach" in addition to fitting into current workflows.

Engineering managers can handle the interoperability between blockchain and current supply chain management systems by utilizing systems thinking. This entails managing the complexity of contemporary supply chains, which may comprise a wide range of goods, services, vendors, and clients, as well as making sure the blockchain platform can interface with legacy systems and bring stakeholders together around common objectives.

Emphasizing Scalability and Security: In order to handle the volume of transactions that are typical in a supply chain, engineering managers must also scale blockchain solutions. Additionally, they need to guarantee that the blockchain's security does not jeopardize the speed and efficiency of transactions. Process optimization requires overcoming technological constraints without compromising data integrity.

Encouraging Adoption and Change Management: One of the other responsibilities of the engineering management principles is to organize change management and encourage the supply chain to adopt blockchain technology. This entails informing interested parties about the advantages of blockchain technology, responding to worries about automation displacing jobs, and assisting staff members in adjusting to new procedures. To guarantee a seamless transition to the new systems, engineering managers must organize training and offer assistance.

Data-Driven Decision Making: An engineering management approach also highlights the significance of making decisions based on data. The massive volume of data produced by supply chain transactions becomes verifiable and unchangeable with blockchain. Engineering managers can use this data analytically to make better decisions, more accurate demand forecasts, and improved inventory and logistics management.

Continuous Innovation and Improvement: The goal of engineering management is to constantly innovate and improve rather than merely uphold the status quo. Engineering managers can improve performance by continuously evaluating and optimizing supply chain procedures with blockchain. Because all parties involved in the supply chain have real-time access to the same

information, blockchain's transparency encourages cooperation and partnerships while also spurring group efforts toward efficiency and innovation.

Aligning with Organizational Goals: Lastly, the engineering management principles guarantee that the blockchain integration is in line with the organization's overarching aims and objectives. Whether it's lowering expenses, boosting sustainability, or improving efficiency, an engineering manager will make sure the blockchain initiative helps the business achieve its strategic goals.

To sum up, supply chain management can effectively incorporate blockchain technology only if engineering management principles are applied. It calls for a harmonious blend of strategic systems thinking, in-depth technical knowledge, and a laser-like focus on process optimization. By utilizing these guidelines, engineering managers can effectively handle the obstacles and intricacies involved in incorporating a revolutionary technology such as blockchain, thereby realizing its full potential to bring about a revolution in supply chain management.

6.3 Thesis Conclusion

This thesis explores how blockchain technology might improve supply chain operations and lead to sustainability, transparency, and efficiency. To this end, a thorough literature review was conducted. We have studied the complex problem from the engineering management point of view, paying particular attention to process optimization in the environmental, social, and economic domains.

This research has demonstrated that blockchain technology, which provides unmatched efficiency and transparency, has great potential for sustainable supply chain management. Through the process of combining industry reports, case studies, and scientific publications, we have determined how blockchain technology can support sustainable business practices.

Our research findings indicate that supply chains can significantly increase accountability and traceability by incorporating blockchain technology. This leads to social benefits by guaranteeing fair trade, economic gains by decreasing fraud and increasing efficiency, and environmental benefits by improving resource management.

Our approach has offered a comprehensive perspective that will contribute to academic discourse and practical application by considering qualitative methodology. We have stressed the significance of carefully choosing data sources, depending on reliable scholarly databases and standards that guarantee precise and relevant data.

The difficulties in putting blockchain technology into practice, such as its technical complexity and the requirement for standardization amongst various supply chain stakeholders, have also been brought to light by our research. Furthermore, although recent works have been given priority due to their original insights, blockchain is a developing field, and ongoing research is required to stay up to date with its developments.

Our study has important applications for academics, practitioners, and policymakers. Adopting blockchain technology can be a wise decision for professionals trying to boost their brand's reputation and get a competitive edge.

Academics can delve deeper into the socio-technical aspects of blockchain adoption, and policymakers can discover a way to successfully enforce regulatory compliance through this technology.

The author has to admit that this study has limitations even with its potential. Because blockchain technology is developing so quickly, it may be necessary to reevaluate current conclusions in the near future. Moreover, the focus on literature might not fully convey the range of regional implementations and the real-world difficulties.

After doing this research we realized that Blockchain technology has the potential to improve supply chain management. It provides a step toward more transparent, efficient, and sustainable supply chains that can satisfy today's demands for moral production and consumption. The used methodology has provided us with valuable insights into the potential for blockchain technology to transform, but this potential must be carefully navigated through technical complexities, stakeholder engagement, and seamless integration with current systems.

Future developments in digital technology will surely bring forth additional innovations that sustainable supply chain management can use. The goal of this thesis is to establish the groundwork for future investigations that will hopefully improve supply chain efficiency, sustainability, and transparency in the real world.

This thesis represents a critical first step toward realizing blockchain technology's promise in supply chains. It indicates a time when efficient, sustainable, and transparent supply chain practices will be the standard rather than an unrealistic goal. We are at the beginning of a time when supply chain management, with the strategic application of modern technologies like blockchain, can effectively represent the values of fair trade, environmental stewardship, and the circular economy.

By the time this exploratory journey comes to a final stage, it is obvious that blockchain is more than just a piece of technology; it is a systemic change catalyst, a link to a more sustainable future, and evidence of the effectiveness of interdisciplinary research in engineering management. The author hopes that the discussions, conclusions, and frameworks offered here contribute to the academic community and industry corridors that aim to create a more liable and transparent global marketplace.

These talks make it imperative for businesses to foster an innovative and ever-learning culture in addition to keeping up with technology developments. This culture will make it easier for supply chains to integrate blockchain and other cutting-edge technologies, allowing companies to quickly adjust to shifting consumer needs and legal requirements.

The potential for generating value within supply chains is further enhanced by the convergence of blockchain technology with other innovative technological advancements like AI, IoT, and smart contracts. These integrations may improve the ability to make decisions, automate procedures even more, and give users more control over complicated supply chains.

The efficient use of blockchain technology needs a strong alignment with fundamental concepts like systems thinking, process optimization, and change management, according to engineering management theory. Companies need to support these ideas to manage the challenges that come with this kind of integration.

While this research has focused on how blockchain can change supply chains, it is important to remember that the wider social and moral implications of its adoption cannot be undervalued. It is the duty of the companies implementing this technology as well as the end users who will gain from it to create a cooperative atmosphere where transparency and sustainability are not only welcomed but demanded.

This study has shed light on how blockchain technology may transform supply chains. The foundation for understanding every aspect of blockchain's contribution to increasing sustainability, transparency, and efficiency in the global supply chain has been established. The author anticipates that understanding this thesis will motivate more investigation and encourage users to fully utilize the potential of the technology. Informed choices, moral behavior, and a dedication to long-term value creation will define the future of sustainable supply chain management. This can be achieved by creating an ecosystem that supports innovation and knowledge sharing.

It takes a marathon, not a sprint, to integrate blockchain into the supply chain. With the belief that the path laid out in this thesis will function as a roadmap for the solid commitment to excellence in supply chain management, the mantle is passed to the next generation of thinkers and doers. The promise of blockchain technology brightens the horizon, and it is up to the international community to approach this horizon with resolve and foresight.

The author is eager to observe how these insights are operationalized, the difficulties that are faced, and how they help to guide the global supply chain toward a more resilient and sustainable future, all in the spirit of constant improvement and cooperation. This thesis concludes, but it also serves as a call to action for a new, data-driven, morally grounded, and technologically empowered era in supply chain management.

Upon the conclusion of this thesis, we encourage future researchers to expand on our discoveries, carry out empirical investigations that can support the theoretical frameworks, and investigate the long-term effects of blockchain technology on supply chain management. Industry-academia cooperation is crucial to close the knowledge gap and collaborate on solutions that are advantageous to all parties involved.

Ultimately, this thesis serves as evidence of the effectiveness of multidisciplinary research and its potential influence on the real world. The author hopes that this work will be of interest to academics as well as business leaders who are driving change in their respective fields. Let this conclusion act as the foundation for more innovation in the ever-evolving field of supply chain management, where blockchain technology is a key tool for establishing the requirements of a more ethical, transparent, efficient, and sustainable global economy.

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