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Leveraging the Internet of Things and Blockchain Technologies for Sustainable and Transparent Supply Chain Management

School of Technology and Innovations
Master's Thesis
Industrial Management

VAASA 2024

UNIVERSITY OF VAASA

School of Technology and Innovations

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Title of Thesis: Leveraging the Internet of Things and Blockchain Technologies for Sustainable and Transparent Supply Chain Management

Degree: Master of Science in Economics and Business Administration

Program: Industrial Management

Supervisor: Emmanuel Ndzibah

Secondary Supervisor: Ville Tuomi

Year: 2024 **Pages:** 71

ABSTRACT

The thesis focuses on correctly applying and implementing Internet of Things (IoT) innovation and blockchain technology in supply chain management, emphasizing sustainability and transparency. Leveraging innovative applications like IoT and blockchain appears to be one effective way to achieve this aim. These platforms provide unique benefits of information technology for supporting sustainable supply chains from the perspective of data-sharing capabilities and value chain integration to drive efficiency and transparency.

Ten participants were asked to fill out a self-administered questionnaire, which included questions related to the frequency of technology usage, the implementation of IoT and blockchain in supply chain management (SCM), perceptions about using these technologies in SCM, and challenges encountered while using them. The research aimed to answer the question: How do the Internet of Things and blockchain technologies contribute to enhancing sustainability and transparency within supply chain management practices? After completing the questionnaire, preliminary interviews were conducted with the participants to better understand their ideas and opinions.

This paper establishes a current and widespread awareness of IoT and blockchain systems, coupled with significantly low implementation rates and divergent views on their usefulness. Challenges in deploying these technologies include high cost, data privacy, data sharing, integration and coordination, and regulations. While there is little disagreement on the positive changes that are seen as possible with the help of these technologies, there is general agreement that these technologies have potential benefits in enhancing transparency and sustainability within supply chains.

Future studies could focus on creating financial inducements and organizing specialized training to overcome implementation barriers like high cost, data privacy, regulatory concerns, and skill personnel gaps. Additionally, the research could recognize practical applications for dealing with the challenges and apply the best methods and real-world advantages of employing IoT and blockchains for sustainable and transparent SCM.

KEYWORDS: IoT, Blockchain, Supply Chain, Logistics Management, Sustainability, Transparency

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Abbreviations:

ARIMA	**Auto-Regressive Integrated Moving Average**
DF	**Demand Forecasting**
GE	**General Electric**
GIS	**Geographic Information Systems**
GPS	**Global Positioning System**
GSI	**Global Standards Initiative**
IBM's	**Other Business Name: International Business Machines Corporation**
IoT	**Internet of Things**
LVMH	**Louis Vuitton Moët Hennessy/ Moët Hennessy Louis Vuitton**
NFC chips	**Near Field Communication chips.**
NGOs	**Non-Governmental Organizations**
QR codes	**Quick Response codes.**
RBV	**Resource-Based View**
RFID	**Radio Frequency Identification**
RNNs	**Recurrent Neural Networks**
SC	**Supply Chain**

SCN	**Supply Chain Network**
SCM	**Supply Chain Management**
SSCM	**Sustainable Supply Chain Management**
TBL	**Triple Bottom Line**
TCE	**Transaction Cost Economics**
TSA	**Time Series Analysis**
WSN	**Wireless Sensor Network**

1. Introduction

1.1. Background of the study

In today's world filled with increasing interconnectivity and environmental consciousness, achieving sustainability in supply chain management (SCM) is critical for businesses across various industries. Leveraging innovative applications such as the Internet of Things (IoT) and blockchain to enhance the concept further seems to be one of the effective ways to accomplish this goal (Rejeb et al., 2019). From the perspective of value-chain integration and data-sharing capabilities, many provide information technology benefits, especially for supporting sustainable supply chains (SSC) and increasing system efficiency and transparency (Simske et al., 2021). Besides, by using the IoT, wireless sensor networks (WSN), Radio Frequency Identification (RFID) technology, cloud computing, and other sophisticated tracking and monitoring systems can have real-time visibility over the supply chain process (Landaluce et al., 2020). This makes it easier to identify areas needing improvement, reduce avoidable costs, and show respect for the environment in production, use of resources, and disposal of waste.

Understanding the application of IoT and blockchain in sustainable supply chain management (SSCM) could become essential for companies and organizations looking to adopt and execute sustainable and socially responsible solutions. The data produced by the sensors can be recovered and used to organize an information infrastructure that supports planning and decision-making (Shambulingappa & Pavankumar, 2017). The research aims to recognize the impact of IoT and blockchain technologies in supporting innovative and sustainable supply chain management.

1.2. Research gap, question, and objectives.

Databases used	Several research databases were used to conduct the gap analysis, and the most popular ones were Science Direct, Scopus, Springer Link, and Google Scholar. These databases were selected because they emphasize publications in the form of research articles, the interdisciplinary nature of the publications, conference papers, and the topics of IoT, blockchain, and sustainable supply chain management.
Scope and time horizon	The study was limited to publications published within five years (2019-2024) to collect relatively current information. The research that explored IoT and blockchain technologies to address SC issues with an emphasis on sustainability and transparency was more focused.
Synthesis of results	The synthesis of the findings involved a critical analysis of existing knowledge to identify trends, perceived difficulties, and research deficiencies. The trends and future research areas were highlighted after analyzing the research articles, conference papers, and reports. The synthesis process included segregating the literature about the research theme and obtaining information that elaborates on the possibility of IoT and blockchain in sustainable supply chain management.

The current state of research	• Existing research shows a rising trend in the literature carrying studies on implementing IoT and blockchain in SCM (Kazemi et al., 2019). • Research has been conducted regarding utilizing IoT and blockchain in supply chains, both in unison and separately, to optimize supply chains and their operations (Munir et al., 2020). • Research also indicates these technologies may help combat inventory and product identity issues.
Research gap	Although the number of studies that consider the use of IoT and blockchain in the supply chain context has been expanding in recent years, the interaction and combined consequences of these technologies on their ability to contribute to the sustainability of supply chains and achieve the goal of supply chain transparency remain an understudied area. Although some previous studies reflect on the advantages of IoT tracking and monitoring systems or blockchain transparency, there is still a lack of an overall systematic model combining IoT and blockchain to provide comprehensive solutions to modern SCs' sustainability issues. Moreover, the current research appears to be predominantly theoretical, and many of the proven hypotheses were investigated based on case studies or in specific industries; thus, the current research findings may not be applicable across various industries and diverse supply chain settings. Thus, there is a lack of significantly developed empirical research

	that would analyze the integration of IoT and blockchain to improve environmental performance, the extent of sustainable social responsibility, and ethical sourcing across the supply chain (Queiroz et al., 2020). This study identified a gap in the literature regarding the integration of IoT and blockchain in supply chains while proposing new ideas for future research about IoT and blockchain integration that can positively contribute to supply management systems that stem from this gap.

Table 1: Gap analysis.

This study addresses the research question: *How do the Internet of Things (IoT) and blockchain technologies contribute to enhancing sustainability and transparency within supply chain management practices?*

The objectives of the study are:

1. To analyze and identify the challenges and limitations of current supply chain management practices, focusing on sustainability and transparency.
2. To explore the principles and functionalities of the Internet of Things (IoT) and blockchain technologies in supply chain sustainability management to enhance transparency.
3. To explore how IoT and blockchain technologies offer better transparency and tracing of products in supply chain management.
4. To determine the critical success factors crucial for achieving IoT and blockchain implementation successfully in supply chain and logistics management, especially regarding sustainability.
5. To suggest practical recommendations and strategies for seamlessly integrating IoT and blockchain technologies into supply chain frameworks, emphasizing the promotion of sustainability and transparency.

1.3. Definitions and scope of the study

IoT: IoT refers to connecting objects, vehicles, and many other appliances by using an internet link to allow them to share information (Landaluce et al., 2020). These include sensors, wearables, smart meters, and applications and gadgets based on technology such as industrial machinery. For example, in SC and logistics, IoT devices may be installed in shipping containers to track location, temperature, humidity, and product conditions in real-time (Ben-Daya et al., 2019). The research aims to identify the IoT secure architecture and protocol in the supply chain applications that help eliminate such risks and ensure data authenticity.

Blockchain: Blockchain is a distributed and decentralized technology that maintains a growing list of records or transactions, and it contains an ever-increasing list of versions called blocks (Rejeb et al., 2019). Every transaction is grouped into a block and connected to the next to form a series of blocks, also known as a chain. Blockchain has the potential in supply chain management to improve the visibility of the product through the supply system by creating accountability of transactions through means such as the use of smart contracts and ensuring that there is an immutable record that records the movement of the product throughout the supply chain from the manufacturer to the consumer (Cole et al., 2019).

Specifically, regarding Blockchain, this thesis will focus on scalability problems and energy concerns. The research proposed for the study will seek to look at secure and large-scale blockchain applications and optimize consensus algorithms to support proportional supply chain rollouts efficiently.

Supply Chain: A supply chain is a system that defines all the organizations, resources, activities, and technologies used to provide goods and services, starting from the point of supply to the consumer (Shambulingappa & Pavankumar, 2017). IOP also applies to procurement, manufacturing, transportation, and warehousing throughout the product's lifecycle (Queiroz et al., 2020). A supply chain, for example, a smartphone, consists of suppliers of its various parts, assembly factories, logistic companies, and stores.

The scope of this research on the supply chain is limited to interoperability between systems. According to Queiroz et al. (2020), the research explores using blockchain integration with big data to solve complex data integration issues and ensure stakeholder interoperability.

Logistics Management: Coyle et al. (2021) define logistics management as coordinating materials, parts, information, and services cost-effectively and efficiently to imperative customer-facing locations. It includes processes such as order processing, storage and picking, stock tracking, and product movement from one location to another. For example, a logistics manager might attempt to reduce expenses by calculating the most appropriate channels and ways to convey their goods (Kazemi et al., 2019).

On Logistics Management, this research will not address all-around inefficiencies but will focus on last-mile delivery. The study intends to resolve this by establishing blockchain-based logistics and IoT-based tracking systems to optimize last-mile delivery routes.

Sustainability: According to Koberg and Longoni (2019), sustainability can be described as using resources in the present in a manner that does not adversely affect the acceptability of the same resources if used by the succeeding generations. Achieving sustainability is best described as optimizing the

efficiency of economic concerns, the protection of the environment, and the welfare of society for future sustainability and relevancy. In the context of SCM, sustainability objectives can be linked with green supply chain management by controlling carbon emissions, waste management, and unfair labour practices throughout the chain (Shambulingappa & Pavankumar, 2017).

As far as Sustainability is concerned, this research has been restricted to the issues related to the evaluation and, thus, the quantification of sustainable endeavors. The study focuses on how IoT and blockchain can monitor and authenticate sustainability commitments across the value chain, providing insight into sustainable performance.

Transparency: Transparency means to bring light, clarify things, or reveal information or the execution of certain activities or functions (Queiroz et al., 2020). In supply chain management, transparency can be understood as sharing specific info with the SC members and other stakeholders, including information regarding product source and origin and how the products are made and sold to consumers (Logan, 2020). For example, an organization may use ‘stringent sourcing’ to make information about suppliers, their labour treatment, and their environmental effects publicly available.

Regarding Transparency, this thesis excludes details of information disparities and trust breakdowns between partners in a supply chain. It is designed to address this by utilizing real-time tracking of blockchain-based transparency tools and IoT sensors for supply chain visibility to improve stakeholders' confidence.

1.4. Research process and data analysis

A qualitative research design will be employed to achieve the objectives of this study. This involves gathering data from publications, research studies, papers, and cases that pertain to how the IoT and blockchain technology enable sustainability in supply chains and logistics. The information will be gathered from scientific journals, business and industry-relevant magazines and newspapers, conference publications, government documents, and other reputable online sources.

This enables evaluation of current knowledge in the given field, making it easier to gain a broad and profound understanding of the topic, besides helping derive valuable conclusions and recommendations. The thesis will testify to using the qualitative methodology approach for subject research and investigation. The initial objective is to determine how IoT and blockchain can improve the supply chain's transparency and sustainability to recommend how they can best be deployed.

Data for this research will be collected through a qualitative method involving questionnaires and observations. The interviews will be held online, allowing data to be collected from an unbiased sample. Fifteen industry managers will be reached through the online platforms to recruit for the study. Another approach is structured interviews to get detailed information from the available supply chain management, IoT, and blockchain.

1.5. Structure of the thesis

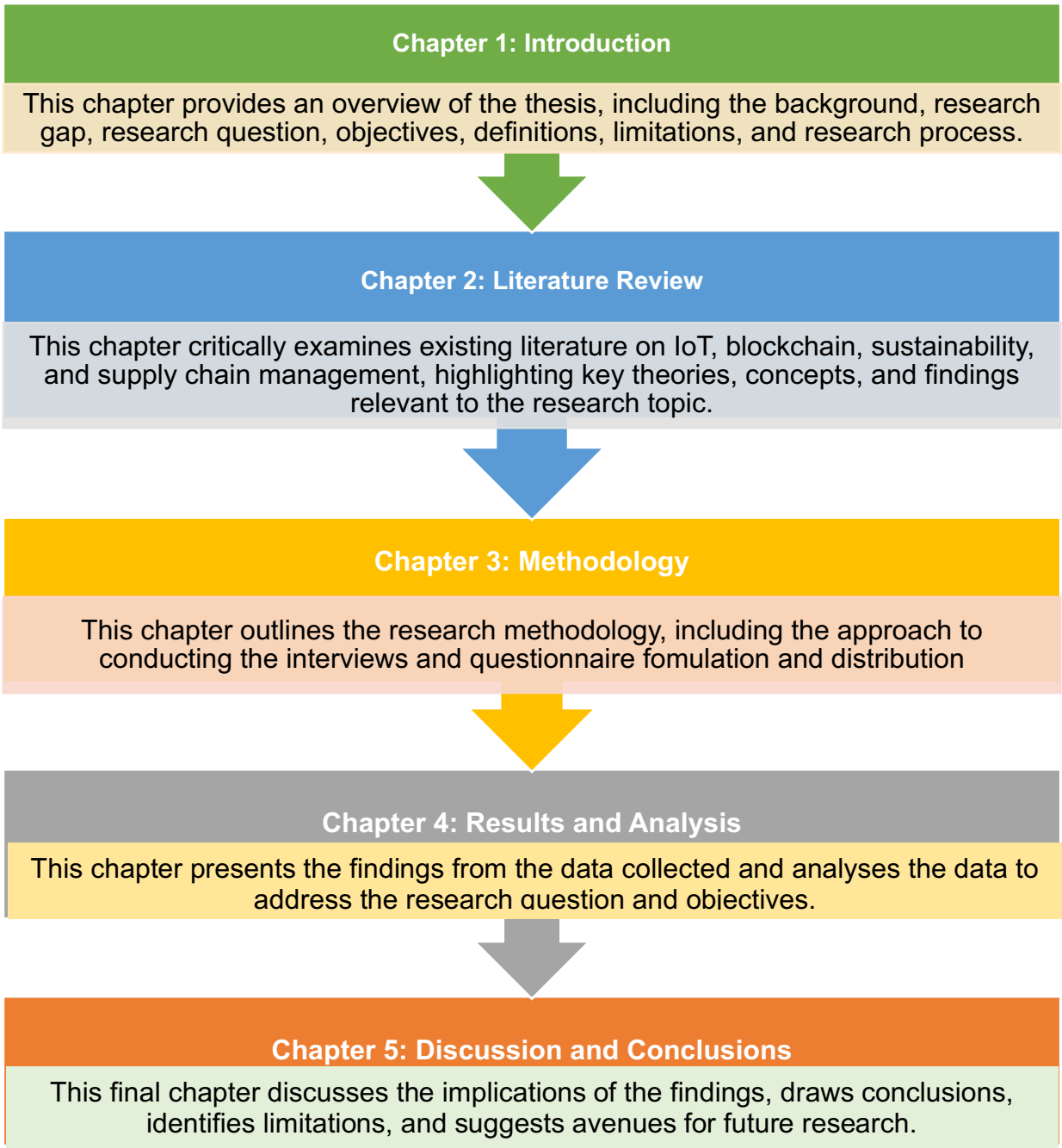

Figure 1: Structure of the thesis.

2. Literature review

This chapter reviews the existing studies on the Internet of Things (IoT), blockchain technology, sustainability, transparency, and supply chain management. This involves a comprehensive and systematic review of primary theories, concepts, and empirical findings from various theoretical frameworks pertinent to the research topic. This review outlines gaps, trends, and controversies to advance the research's theorization and empirical analysis in line with the approach. Therefore, using knowledge from existing theories and literature, this chapter explicates the benefits, challenges, and prospects of utilizing IoT and blockchain in enhancing SC strategies for sustainability purposes. The authors considered and analyzed 10 peer-reviewed articles in this review to provide an extensive view of the supply chain processes. The table below shows the five major works used for definitions and propositions.

Author	**Definition**	**Proposition**
Altay & Pal, R. (2023)	Coping in supply chains refers to strategies an organization uses to mitigate disruption.	Effective coping mechanisms in supply chains enhance resilience and mitigate the impact of disruptions.
Koberg & Longoni (2019)	Sustainable supply chain management incorporates sustainability principles into supply chain functions in the global economy.	Collaborative partnerships across supply chain tiers help to support the successful adoption of sustainable supply chain management strategies.
Del Giudice et al. (2021)	In supply chain management, a circular economy refers to operations that involve closing the loop, where resources cycle back to their original use.	The incorporation of big data analytics serves to improve the circular economy performances of supply chains.

Kazemi et al. (2019)	Reverse logistics in supply chain management focuses on managing product returns and recycling materials.	Efficient reverse logistics processes reduce waste and optimize resource utilization in supply chains.
Khan et al. (2023)	Green supply chain management consists of all the processes geared toward making manufacturing operations environmentally sustainable.	Leveraging organizational resources contributes to implementing green supply chain management practices effectively and efficiently.

Table 2: Articles used for definitions.

2.1. Internet of Things and blockchain technologies

The introduction of IoT and blockchain technologies has transformed various sectors, including SCM, by offering exceptional facilities for data collection, processing, and secure transactions (Munir et al., 2020). In supply chain management, IoT devices include, among many other things, temperature sensors, smart meters, RFID tags, humidity sensors, and GPS trackers. These devices provide real-time tracking of associated assets and stock, additional environmental conditions along the linked supply chain, and generalized control.

Enhanced traceability and transparency are two key benefits of IoT integration in SC. Tracking devices can monitor products via IoT, recording their production, transportation, and delivery locations. Ghadge et al. (2023) claim that it improves visibility by identifying inefficiencies, monitoring the product's history, and ensuring that it corresponds with specific laws and regulations.

On the other hand, IoT plays a crucial role in quality control, maintenance planning, and supply chain monitoring. For instance, Kaliyannan et al. (2023) state that these devices provide continuous environment updates on the equipment's temperature, humidity,

and vibration level to permit industries to have advance notice of quality problems or equipment failure in advance. Real-time data can be used to form predictive maintenance structures that enable the management of organizational assets throughout their lifecycle, decrease the occurrence of acute breakdowns, and, therefore, decrease losses resulting from interruptions of operations. In addition, devices can be implemented through IoT to collect information about the state of products and equipment. This will prevent and correct failures and ensure the necessary quality during transportation and storage. It also makes good business sense to make quality controls proactive and not wait for customers to reject our products, which makes keeping things clean more efficient, other than, of course, making our products of better quality, and therefore making a competitive product in the marketplace.

However, this growth also brings with it concerns about the use of IoT in supply chains, specifically data security and privacy. The Rio de Janeiro Declaration made it clear that the large amount of data produced by IoT devices exposes it to risks such as unauthorized access, data violation, and cyberattacks. Moreover, there is always a question of ownership and management of data, which becomes an issue affecting sharing and communication between supply chain members (Ghadge et al., 2023).

Blockchain technology provides a decentralized and secure, unalterable record-keeping system that helps transparently record transactions (Munir et al., 2020). The blocks are connected through cryptography with the previous block, which makes the process immutable to any modifications. In SCM, blockchain creates immutable records regarding the movement of products, transactions, and contracts, which boosts credibility.

2.2. An overview and theoretical frameworks in supply chain management

According to Munir et al. (2020), critically examining theoretical frameworks brings out key aspects of the mechanisms and drivers of supply chains, which, when practiced in context, inspire effective supply chain management decisions and subsequent performance enhancements. However, it is crucial to note that supply chain management is a broad and evolving body of work that ensures the planning and integration of activities, materials, and information of different entities in the supply of products and services to the end consumers. Presumably, theoretical frameworks in SCM offer the supply chain management perspective and conceptual tools for analyzing different aspects of an organization's activities. This section critically discusses some of the key theoretical frameworks in SCM.

2.2.1. Supply chain integration:

Supply chain integration theory deals with integration and cooperation among individual supply chain members, leading to operational efficiencies and competitive benefits (Munir et al., 2020). Therefore, it proposed that improved interface cooperation between the supplier, manufacturer, distributor, and customer yields better adaptability, lower costs, and improved customer satisfaction. However, there is always a problem of integration, which may consist of info asymmetry, issues with trust, and divergence of interest of the stakeholders. Theoretically, companies such as Apple Inc. apply SCM supply chain integration theory as it involves the proper interaction and integration of the manufacturing firms in its overall internal supply chain network. In collaboration with companies like Foxconn, Apple processes by sharing forecasts, production schedules, or inventory. This kind of operation contributes to the operational synergy and exclusion of various disturbances in the supply chain. Some contemporary issues in supply chain integration are the practical usage of IoT and blockchain to improve the coordination of partners.

2.2.2. Resource-based view (RBV):

The RBV points out the management of resources and capabilities within organizations to attain valuable and strategic resource stock accumulation and a genuine competitive edge (Khan et al., 2023). Concerning SCM, the RBV underscores the importance of physical and knowledge-based assets, including technology, people's capital, and networks, in generating value for supply chain stakeholders. Since competitive environments are always characterized by the availability of many resources, those organizations that can utilize their resources to build organizational competencies and then orientate these competencies with the opportunities of a particular market are likely to be successful. For example, Toyota's strategic approach of establishing long-term bonds with the suppliers, training and development of its human resources, and commitment to making sustainable improvements in its business process are all supportive of RBV that stresses utilizing firm-specific resources for the creation of value addition (Khan et al., 2023).

2.2.3. Transaction cost economics (TCE):

TCE theory studies how organization transactions are governed and the contractual relationships between two or more organizations (Ntale et al., 2022). It implies that firms select governance mechanisms, which include hierarchical control or market-based firms, dependent on transaction-specific attributes like assets and their specificity, the uncertainty of transactions, and the frequency of transactions. In selecting the supply chain strategies, TCE gives an understanding of the make-or-buy decision, choice of suppliers, and risk management plans in the supply chain (Bhatia et al., 2023). One example of an organization that has used this framework is Amazon when structuring governance and contracts for procurement and managing supply chain relationships. One new development in TCE is where digital technology like smart systems and the blockchain are employed in contracts for increased efficiency and better relationships between supply chain partners.

2.2.4. Contingency theory:

Amid the array of organizational culture and management theories, contingency theory notes that no universal model exists for organizing or managing supply chains and that these models are context-dependent (Bai et al., 2023). Contingency theory is used in supply chain decisions, inventory planning, and designing the best logistics networks. For instance, Zara applies this framework to determine its effective and adaptable supply chain solutions, enabling it to meet current supply chain requirements flexibly. Zara has one of the most centralized decision-making processes in the fashion industry and has combined short manufacturing cycle times, enabling it to adjust its production line to meet customer needs and trends (Bhatia et al., 2023). Trends evident in contingency theory are the use of AI in combination with real-time data analysis to enhance the flexibility of the supply chain.

2.2.5. Triple bottom line (TBL):

As highlighted by Yosef et al. (2023), the elements of the TBL strategy have social and environmental components that are not present in mere financial performance indicators. The concept of the triple bottom line within the context of SCM refers to incorporating the sustainability factors in the sourcing, manufacturing, delivery, and disposal of the products to enhance the welfare of all the stakeholders. For instance, Unilever uses this framework to align new sustainability goals in the company structure with existing supply chain practices. Yosef et al. (2023) opine that through the Sustainable Living Plan, Unilever has a plan that considers both environmental and social sustainability, which is the establishment of ambitious targets for the environment and people’s welfare, including smallholder farmers. A recent development in TBL is integrating life cycle assessment tools and blockchain to provide additional tools for tracing and monitoring sustainable supply chains.

2.2.6. Lean and agile supply chains:

It is crucial to mention that lean and agile supply chain theories are distinguished by two key goals of operatively managing a supply chain: productivity enhancement and the closely related increase in supply chain responsiveness (Abdelilah et al., 2023). Therefore, lean and agile servicing have been seen as a twin model that can accomplish the supply chain's compounded goals of effectiveness and adaptability. For instance, Dell's endeavors to make supply chains fast and efficient are concerned with this framework (Abdelilah et al., 2023). Trends currently visible in emerging lean and agile supply chain systems include using Robotics Automation to make the existing channels smoother and more flexible in manufacturing and supplies.

2.3. Sustainable supply chain management practices

Supply chain sustainability is an area that has attracted great interest in today's world due to the adverse ecological and social effects of conventional supply chain operations. The second element of the concept is the sustainability of the supply chain management and the attention paid to environmental, social, and even economic factors within the entire life cycle of supply chain activities. It also outlines concerns such as carbon emission, waste management, ethics, and sourcing, among others, that organizations are also central to for a sighting. Extending the notion, it can be identified that both economic and socio-organizational benefits are associated with sustainable practices in the supply chain, including cost reduction, increased brand equity, and better stakeholder relations (Gruchmann et al., 2023). There are diverse, sustainable supply chain management practices that have been practiced across different organizations, and the outcome has been that they are viable options for realizing environmental and social agendas. This includes green purchasing, low-carbon transportation, cycle economy, ethical buying, transparency, and traceability (Del Giudice et al., 2021).

Transitioning to the use of environmentally friendly products in the supply chain is known as green procurement and is considered the foundation of Sustainable Sourcing. Stakeholders are involved by an organization in having preferred suppliers with poor management regarding energy consumption, waste disposal, or lack of environmental certification. When choosing suppliers or vendors, companies should target those that possess sustainable environmental policies. This will help lower environmental costs associated with company activities, resource consumption, and preservation (Khan et al., 2023). For instance, NGOs such as Patagonia have already advanced numerous great sustainability policies, which cover the entire manufacturing process, namely the supply of materials and the recycling programs, as well as the treatment of employees throughout the whole supply chain.

Considering this, sustainable transport strategies have been seen as proactive in reducing greenhouse gas emissions and enhancing environmental responsibility within supply systems (Ghadge et al., 2023). Reducing the number of transports, fixing and planning transport routes, using environmentally friendly transport technologies, and efficiently shipping transport loads are good ways to minimize fuel consumption for transport operations.

The use of a circular economy in supply chain practices depicts a shift from traditional linear operations to integrated systems that seek to minimize resource consumption and output waste. Re-use, remanufacturing, and recycling support using circular economy strategies that enhance resource conservation and reduce dependency on new material sources (Amala & Sivakumar, 2023). Closed—loop supply chains reduce the extraction of raw materials within the supply chain and increase the use of products and parts so that the business becomes a closed-loop process to regenerate supply chains.

In their study, Del Giudice et al. (2021) explain that ethical sourcing is a critical component of social sustainability in supply chains mainly because it addresses fair

treatment of labor, human rights issues, and treatment of workers. Supplier audits are performed by organizations that include stakeholders in dialogue and incorporate codes of conduct to solve ethical issues and responsible sourcing. Ethically sound procurement practices mean the implementation of the rights of workers and the enhancement of their welfare in supply chain systems. Another key aspect of sustaining supply chain management is transparency and traceability, which clearly show what needs to be done and why it needs to be done. Blockchain technology and IoT enhance the real-time traceability of products and products by their point of origin and manufacturing process.

Incorporating continuous improvement and effective integration is a significant step toward the optimal development of SSCM practices and efforts. Chesborough (2004) further urged organizations to communicate with their suppliers, customers, and other stakeholders to ensure that they induce more innovation and sustainability. It also moves toward supply chain resilience and flexibility for other risks that might affect the company, such as calamities, pandemics, or new regulations.

The crucial aspects require attention when overcoming main barriers and addressing challenges in the sustainable development of supply chain systems. Key issues impacting operations include expense sensitivity, lack of supplier visibility, and compliance requirements. Challenges regarding stakeholders While some organizations may get the support of the stakeholders, others may experience challenges in getting investors to fund sustainable practices (Saraubon et al., 2019). So, the following strategies may be used to overcome these challenges. A more pragmatic approach to sustainability could involve a staged but strategic approach toward making sustainability improvements that have a demonstrable ROI to the organization, working in collaboration with suppliers and business partners to increase sustainability transparency and cooperation.

2.4. Role of IoT in supply chain operations

The Internet of Things (IoT) has brought about significant changes in supply chain management regarding visibility, connectivity, and automation in the supply chain network. With the help of technology like IoT devices, sensors, and data analytics, conventional supply chain activities are enhanced by improving efficiency, cutting costs, and improving organizational performance. The figure below demonstrates the use of IoT devices in different areas of supply chains, including the factory, warehousing, and distribution centers.

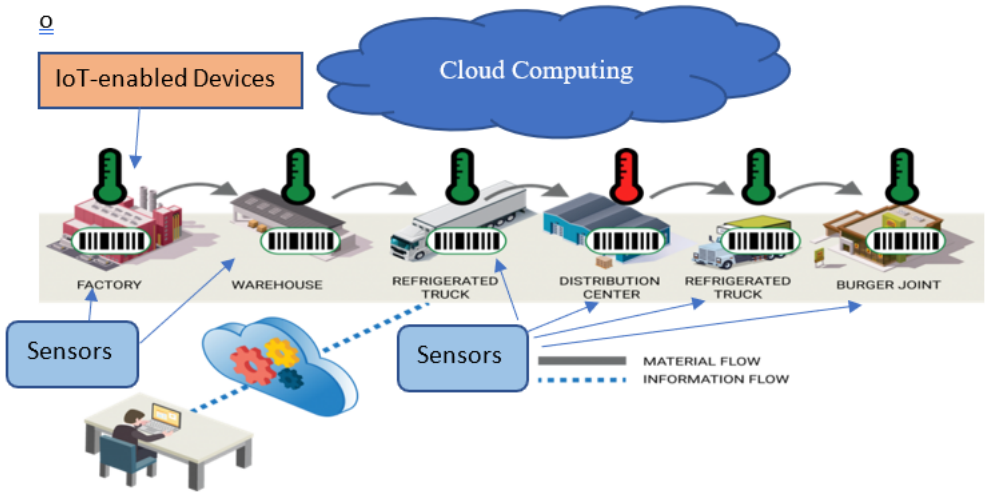

Figure 2: Internet of Things (IoT) in Supply Chain Operations [Source: Embitel.com, 2019).

One of the fundamental roles of IoT in supply chain management is real-time tracking and monitoring. The values from sensors used in IoT or RFID installed in products, containers, and vehicles provide significant information regarding geographical position, temperature, humidity, and many more environmental variables. This real-time shipment monitoring allows the supply chain managers to follow assets from the production departments to the distribution hubs and the consumer (Del Giudice et al., 2021). For instance, current IoT applications like Walmart use IoT to monitor the temperature of perishable products while in transit to check quality and food safety (Sachdev, 2019).

IoT also helps in the undertaking of performance predictive and asset tracking in supply chain systems. Manufacturing companies can enhance their machinery and equipment with IoT sensors to ensure the tracking of performance and signaling of problems before causing a major disruption and, therefore, significant losses. Using sensors, predictive maintenance algorithms such as machine vision distinguish patterns and abnormalities to facilitate proactive maintenance actions. For example, in aircraft engines manufactured by General Electric (GE) Aviation, sensors connected with the IoT are employed to analyze various performant parameters and anticipate future maintenance requirements to reduce service interruptions and increase the efficiency of aviation fleets.

IoT supports proper SCM by providing visibility of the supply chain and allowing better communication and data sharing among supply chain members. Some applications of IoT cloud platforms include sharing data in real-time, especially with suppliers, manufacturers, logistic providers, and retailers, where coordination is needed to share some information (Bai et al., 2023). It enhances issues concerning stocks, consumption patterns, and delivery of merchandise. For instance, organizations, including Procter and Gamble, employ IoT technology to enhance demand forecasting and provide real-time data to suppliers on consumption trends to help in early planning and stocking the necessary supplies.

In addition, IoT offers the capability to manage a supply chain effectively by leveraging real-time insights and achieving automation. It incorporates advanced analytics tools to analyze IoT data to discover glitches, plan better routes, and enhance workflows. Increased usage of automated systems, particularly robotics, that possess IoT sensors favors warehouse operations, order picking, and already optimized inventory management.

2.5. Impact of blockchain technology on supply chain transparency

Blockchain has been discovered to be an exciting technology with great potential for addressing and solving challenges in many industries, including supply chain management. It undercuts traditional efficiency paradigms by decentralizing the process and making it more transparent (Bai et al., 2023).

Another less tangible, but perhaps one of the most extensive, benefits of blockchain technology in supply chains is enhancing transparency across the whole Supply chain network. Blockchain maintains the decentralized ledger for the entire system. Hence, each transaction is safely and securely stored at various nodes, and every change or transaction made is recorded as a nonerasable ledger. Such an approach makes it possible for the stakeholders to perceive how products are processed, transported, and delivered in the various stages of the supply chain and promote trust and increased accountability among the supply chain members.

An example of such an opportunity is Walmart's use of blockchain technology in the food supply chain to increase transparency. Walmart, along with IBM, implemented the Food Trust platform using the blockchain and traced the course of the food products from the farming stage to the shelf placement (Alqahtani et al., 2021). Consumers, for instance, can easily read more about the packaging container through an encoded QR code with information on the source of the product, how it was produced, and the permit it was produced with. The level of information disclosure goes beyond providing consumers with information that will enable them to make proper food choices; it also escalates the standards of food safety and traceability within food supply networks.

Moreover, using blockchain technology, supply chain members can prove the genuineness and sanctity of products and services, thus eliminating supply chain fraudulence. Every transaction on the blockchain has a signature from which the receiver and sender can be affirmed; therefore, the information is credible and resistant

to alteration. This authentication mechanism is beneficial in some industries that require product authentication or originality, like the pharmaceutical and luxury industries, as described by Hannila (2023).

The diamond industry is a good example of how blockchain influences the ability to authenticate. Other businesses, such as De Beers and Everledger, have incorporated blockchain into their operations, affecting the traceability of diamonds from mining rights to the market. Thus, by applying the concept of blockchain, where key data points like diamond cuts and certifications are recorded, stakeholders can ensure that the diamonds purchased are sourced ethically and that cases of conflict diamonds are eliminated.

Additionally, blockchain technology enhances supply chain sustainability by enabling intelligent contractual compliance with the specific ethical and regulatory requirements identified by smart contracts used in the technology. Smart contracts are digital self-executing programs for managing contracts where the terms of the agreement have already been coded into the blockchain. They order the performance of arrangements with other parties by guaranteeing that the arrangements adhere to ethical sourcing policies and labor and environmental policies.

A notable instance of blockchain smart contracts is the partnership between Nestlé and OpenSC to develop and monitor a palm oil supply chain. The paper shows Nestlé can ensure that its palm oil suppliers implement sustainable sourcing practices and deforestation-free pledges by integrating smart contracts within blockchain transactions (Hannila, 2023). The means of automated compliance are efficient Regarding auditing processes, simplifying administrative work, and fortifying the company’s dedication to sustainability.

2.6. Integration of IoT and blockchain in sustainable supply chains

Integrating the IoT and blockchain may offset the challenges of sustainable supply chains. Integrating the IoT technology that provides real-time data management with the blockchain platform that offers a secure record-keeping system will likely transform how organizations manage their supply chains, receive higher levels of visibility with all stakeholders, and have more control over their processes' traceability and efficiency levels. This section will introduce the combination of IoT and blockchain as innovations in sustainable supply chain management, along with the advantages, drawbacks, and consequences for supply chain advancement.

Some advantages of using IoT and blockchain in supply chain management are: The first one is that they both enable the construction of the supply chain digital twin and provide end-to-end product traceability. Smart devices like sensors, RFID chips, and GPS can also capture information at different supply chain echelons, including the supply of raw materials in transit and storage (Saeed & Shoukat, 2023). Captured information, which includes temperature, humidity, location of the product, and the general condition of the products, is safely stored on the blockchain, making it possible for stakeholders to monitor the movement and the status of products with relative ease. It helps increase supply chain visibility but also helps manage disruptions effectively by making quicker decisions, identifying risks, and controlling measures.

An example that can be described from this perspective is the synergized Internet of Things and blockchain in supply chain management in collaboration with Maersk and IBM. Intelligent shipping containers fitted with IoT devices: Maersk organization employed IoT-equipped containers on all the shipments, planning to track factors like temperature, humidity, and other conditions of the containers (Saraubon et al., 2019). Data gathered from these IoT devices is kept securely in IBM's blockchain environment, implying that rightful managing parties are provided real-time perspectives on the position and state of goods in transit.

Besides, with the help of IoT and blockchain, supply chain members can verify and ensure that the products purchased are original, thus solving the issues of fake and deceitful products. By incorporating each IoT device with a digital signature or a cryptographic tag, the aspects link it to the blockchain through a unique identity. This implies that the products cannot be replaced in the supply chain, or the supply levels cannot change at different cycles, thus removing fakes.

It is just as beneficial to give an example of the use of IoT and blockchain to prove that luxury products are genuine. Some luxury brands like LVMH and Louis Vuitton have also incorporated Blockchain technology to help minimize fakes in their products. Each brand's unique signature can include NFC chips or QR codes with details of a respective brand's product safely stored on the blockchain (Saraubon et al., 2019). This way, the customers can use their phones and scan the identifiers to ensure they are buying the actual luxury products as depicted. However, as with disruptive technologies, it is also crucial to identify the risks and opportunities of IoT and blockchain integration for sustainable supply chains.

2.7. Challenges and opportunities in implementing IoT and blockchain in supply chain management

Organizations must consider the following opportunities and challenges when integrating IoT and blockchain into supply chain management.

Opportunities

- Enhanced Visibility and Transparency:

  As discussed above, IoT and blockchain enhance visibility and control in the supply chain since the movement of goods and other critical attributes, such as

product origin and environmental effects, can be traced and confirmed instantly (Gruchmann et al., 2023).

- Improved Traceability and Compliance:
  Blockchain technology has increased transparency in the following way: It can create an unalterable record of transactions, and therefore, products go through end-to-end tracking from the origin to the point of destiny (Sachdev, 2019). This traceability helps in general compliance with legal guidelines, quality measures, and sound purchasing procedures. It minimizes the incidence of fake products and similar problems related to a distorted supply chain.

- Efficiency and Cost Savings:
  Supply chain processes are enhanced through IoT devices by removing excess intermediaries and automating general processes. Smart contracts and other automated transactions are possible using the blockchain, thus eliminating the middleman and, hence, the formation of transaction costs (Saraubon et al., 2019).

- Innovation and Competitive Advantage:
  Integrating IoT and blockchain ensures a better and more sustainable way of operating since it improves the organization's current position in the market (Saeed & Shoukat, 2023).

Challenges

- Complexity of Integration:
  Challenges may surface in the integration process because of compatibility problems between the latest software and the older system, Compatibility issues

in the integration process of different technologies, and problems that may come from incompatibilities of complex technologies an organization uses.

- Data Security Concerns:
  They also create extreme volumes of data, and protecting against cyberattacks and unauthorized use of this data is daunting (Sachdev, 2019).

- Scalability:
  While it is relatively easy to implement IoT and blockchain solutions in scenarios involving a few sources and transactions, scaling the solution to the whole supply chain network is more complicated.

- Regulatory Compliance:
  Specifically, compliance with data privacy laws, including GDPR and other IoT and blockchain implementation standards, represents a challenge for organizations. Complying with the rules and, at the same time, using promising technologies that can improve organizations' financial and non-financial performance is a factor that can help reduce legal and reputational risks (Saraubon et al., 2019).

2.8. Summary of theoretical framework

It can be concluded from the current literature that IoT technologies have brought about increased levels of visibility throughout the supply network, real-time tracking and control, as well as monitoring of assets and effective communication. Additionally, blockchain enables highly secure and transparent operations of queries, as well as the protection of data integrity and trust among the supply chain members (Kaliyannan et al., 2023). Nevertheless, some issues like data security, the problem of scaling, and compatibility with other networks are the main factors that discourage more people from using the OCC. Green purchase and supply, circular economy, and responsible sourcing are keywords of today's supply chains, reflecting the organization's concern with environmental and social impacts. Despite the problems identified, there are great opportunities for innovation with IoT-Blockchain integration to increase supply chains' sustainability, transparency, and efficiency.

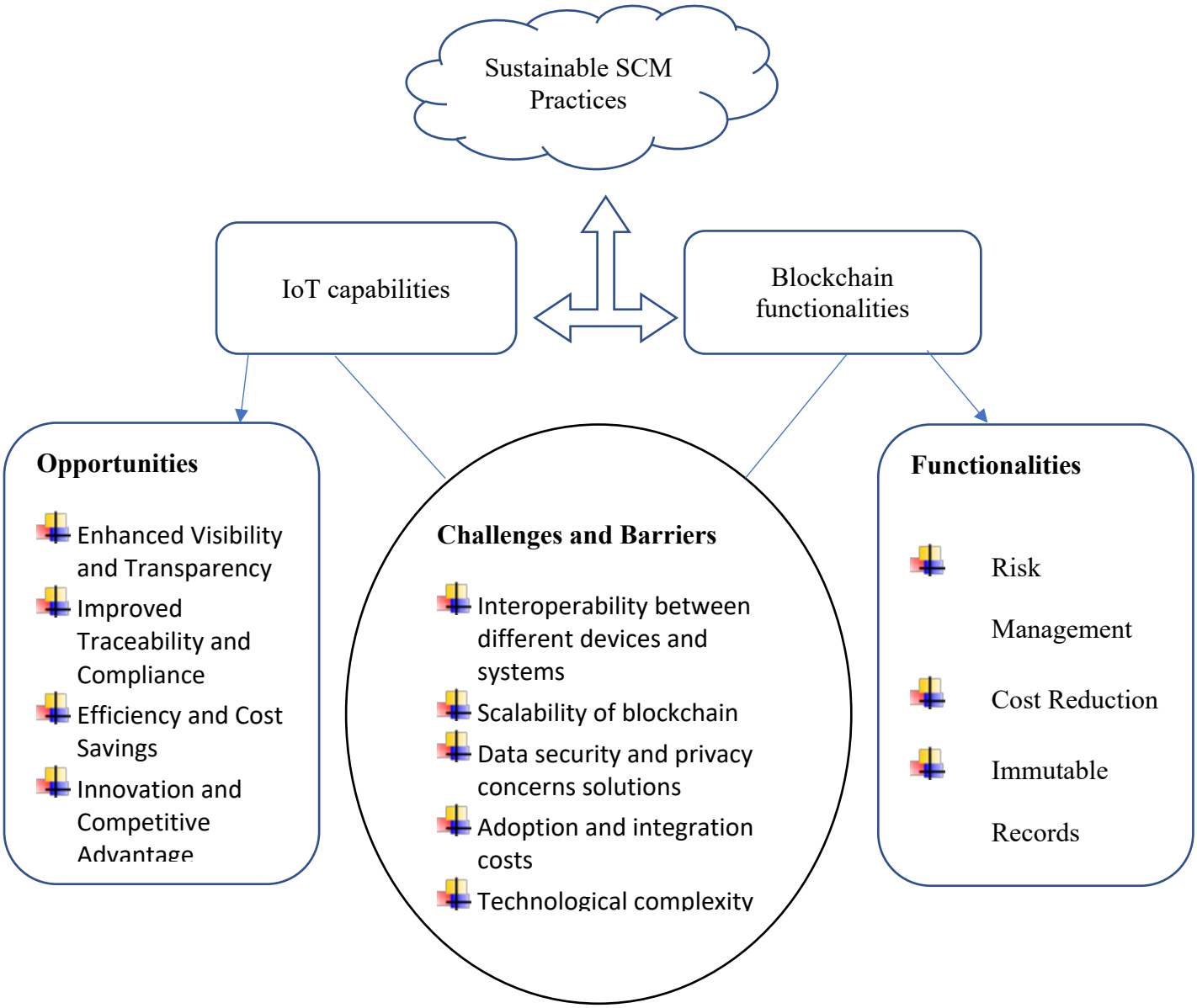

Figure 3: The IoT capabilities and blockchain functionalities.

3. Methodology

This chapter explains how the data was collected and analyzed to answer the research question: How do the *Internet of Things (IoT) and Blockchain technologies contribute to enhancing sustainability and transparency within supply chain management practices?*

3.1. Research process

In this research, the process begins with identifying the research problem and the research question. A literature review is conducted to formulate a conceptual framework. Then, research methods are identified, and interview questions are constructed for comprehensive data collection. For the interviews, open-ended questions are used, while Likert point scales are employed in the online questionnaire to ensure an approach that leaves no room for any data gaps. The collected data is then analyzed using a thematic approach. The figure below demonstrates the research process.

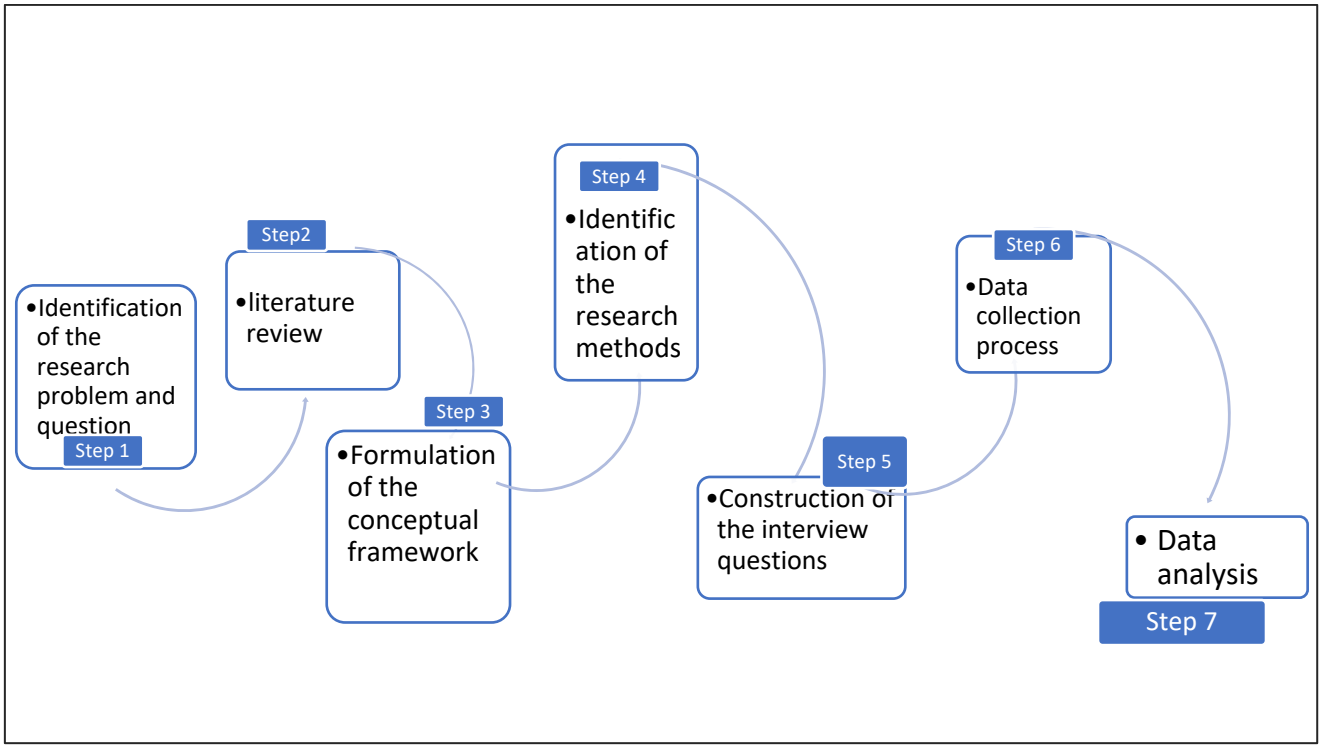

Figure 4: Research process.

3.2. Research design

This research employs a qualitative approach. This approach is used when either no or insufficient research is available to support or counter the effectiveness of a technique. A qualitative research design was chosen for its ability to explore complex phenomena, such as stakeholder perceptions and experiences, which are central to understanding the implementation and impact of leveraging IoT and blockchain in supply chain management for sustainability and transparency (Kirby et al., 2020).

Moreover, the project applies a descriptive research design, including a minimal intervention technique to cover up the biases in the analyzed materials. This routine will help elucidate the parameters of the investigated material; thus, it will become possible to explain the events or the processes thoroughly. Exploratory research is a versatile tool that deals with diverse research problems. It covers a broad spectrum of facts and

is universally conducive to generating hypotheses on any specific category. On the other hand, most of the experiments at this design stage allow the researcher to explore the established ideas and bring forth more precise research questions (Tandon et al., 2021). Moreover, the employed sample size is usually small, making it possible that the results cannot be generalized to the population. This, once more, ensures that an exploratory design is suggested for this study.

3.3. Understanding research approaches: Qualitative vs. quantitative

Aspect	**Qualitative research**	**Quantitative research**
Nature of data	Data is non-numerical and descriptive, focusing on meanings, opinions, and experiences (Kirby et al., 2020).	Data is numerical and statistical, aiming for measurement and quantification.
Research objective	Seeks to explore, understand, and interpret phenomena in-depth.	Aims to test hypotheses, establish relationships, and generalize findings.
Sampling technique	Typically, purposive or snowball sampling focuses on select individuals or groups (Thunberg & Arnell, 2022).	It relies on random or stratified sampling to ensure the representativeness of the population (Sanchez et al., 2023).
Data collection methods	Utilizes methods such as interviews, observations, and focus groups to gather rich, contextual data.	Employs surveys, experiments, and structured observations to collect standardized data from large samples.

Analysis approach	Involves thematic, content, or narrative analysis to identify patterns and themes.	Utilizes statistical analysis, such as regression or correlation, to quantify relationships and test hypotheses (Thunberg & Arnell, 2022).

Table 3: Research approaches.

This thesis adopts a qualitative approach to understand better people's experiences in the industry and their suggestions for encouraging sustainable and transparent supply chain management through IoT and blockchain technologies (Tandon et al., 2021). According to Taherdoost (2021), data collection tools, including interviews and observations, create a platform for probing detailed information from persons in the industry. Therefore, interviews can help create rapport with the participants and help them understand the challenges and benefits organizations get from leveraging IoT and blockchain technologies. With social media, interviews can be organized with much flexibility for the participants (Taherdoost, 2021).

Things like IoT and blockchain in supply chains can be captured entirely by adopting a qualitative approach that allows for assembling the complex and rich environmental factors and the subtle insights that shape the implementation and impact of the IoT and blockchain in supply chains (Kirby et al., 2020). Employing qualitative data analysis techniques that are theme-based, such as the thematic analysis, will be pivotal in identifying key aspects and patterns in stakeholders' perspectives; the latter will let us acquire a deeper comprehension of the mechanics of the supply chain technologies in support of sustainable and transparent practices (Newman & Gough, 2020). However, this approach aligns with the spirit of research on an exploratory nature since it allows for a thorough examination of the topic from different angles.

3.4. Construction of the interview questions

Guided by the research question and the objectives, ten interview questions were developed to cover the research question and help achieve the objectives comprehensively. The interviews were intended for persons in the industry and those who have already implemented IoT or blockchain technologies in the SC. As indicated in the section on the sample and sample size, the research employed 10 participants for the interviews. The interview questions covered different aspects, including the adoption processes, pitfalls, costs and benefits, environmental impact, applicable technologies, and stakeholders' views (See Appendix). Closed-ended questions were not intended to be used as much as open-ended ones, immediately allowing detailed responses and completing the interview discussions. Also, the problems formulated in this survey were simple, short, and relevant for the participants' meaningful participation in the investigation and achievement of the research objectives. The ten interview questions are listed in the appendix.

3.5. Data collection and the sample

Data for this research was collected through a qualitative method involving questionnaires and observations. The interviews were held online, making collecting data from an unbiased sample easy. Although 15 industry managers were reached through the online platforms, only 10 participants were recruited for the study. The participants were recruited via online channels, such as Facebook, LinkedIn, and Google Communities, targeting groups within the supply chain management communities. Another approach is structured interviews to get detailed information from the available supply chain management, IoT, blockchain, or companies and history and to gather information related to technology adoption, finance, and policy (Kirby et al., 2020).

Participants were selected from the supply chain management community via online platforms like Facebook, LinkedIn, and Google Communities. The sampling technique was convenience sampling, where individuals readily available and accessible online were recruited. The sample size of 10 participants was determined based on feasibility and resource constraints. Limitations include potential bias towards individuals active on online platforms and limited generalizability.

The reason for using interviews and questionnaires is twofold: Firstly, interviews provide an opportunity to examine the participants' understanding, experiences, and famous views in detail, leading to qualitative data that can give more profound knowledge on research matters. This approach is crucial for comprehending supply chain issues and the surrounding, yet daunting complexities often associated with adopting IoT and Blockchain technologies (Thunberg & Arnell, 2022).

3.6. Analysis approach

This research employed a thematic analysis approach to analyze the interview and questionnaire findings comprehensively. Among the dominant techniques that will be applied for analysis is the mind mapping technique. Some of the benefits of Mind Mapping include identifying the various themes of analysis and their connections, helping in the conceptualization of the analysis process. By obtaining information, assuming positions and roles, and applying patterns identified during data immersion and constant comparison, themes will evolve progressively as more data is analyzed and code conventions emerge from findings (Kraus et al., 2022). These will be generalizable themes and patterns that will serve as broader guides for more excellent interpretation and abstraction of data (Peel, 2020). Further, working thematic maps or matrices will be

created to identify how different themes are related to different sub-themes easily. In this manner, the research aims to reveal findings that help support further knowledge on sustainable supply chain management through IoT and blockchain technologies (Tandon et al., 2021).

3.7. Ethical considerations

Some of the ethical issues that are of significant concern in this research are: The right of participants to self-consent should be respected; every participant's data collected should remain a secret and protected; and any possible harm that can be inflicted on participants should be avoided to the greatest extent possible. Appropriate informed consent was obtained from the participants regarding the study objectives and their voluntary participation. To ensure the participant's identity is not revealed and data protected, anonymity measures were taken and ensured. Where applicable, institutional review board (IRB) or ethics committee approvals were sought to conform to the rules and standards on ethics in conducting research, with due regard to the participant's rights and welfare at all times. However, to ensure that there is no compromise in academic integrity and no form of plagiarism, there shall be worthy and proper reference and acknowledgment of sources used. In cases of proven conflicts of interest, the information will be disclosed, and the research shall proceed with the highest levels of professionalism and integrity.

4. Results and analysis

This chapter analyses the findings from both the interviews and the questionnaire distributed to the participants online. The analysis identifies different themes and then discusses them as distinct themes for each interview. Question. The table below summarises the findings.

4.1. Results from the interview questions

Themes from Interview	Responses
1. Can you describe the current challenges and limitations you encounter in supply chain management practices concerning sustainability and transparency?	When asked about the current challenges and limitations in supply chain management practices concerning sustainability and transparency, most participants argued that one of the main issues is the lack of visibility across the entire supply chain. This includes difficulties in tracking the origin of raw materials, assessing environmental impacts, and ensuring ethical labor practices. Other challenges cited include the complexity of global supply chains, inconsistent regulations, and the need for better data sharing among stakeholders.
2. What are the main barriers or obstacles you foresee in adopting and	Regarding the principles and functionalities of the Internet of Things, in the context of supply chain sustainability and transparency, most participants highlighted that IoT enables the connection of physical objects to the Internet, allowing for real-

integrating IoT and blockchain technologies into existing supply chain frameworks?	time monitoring and data collection. Blockchain, on the other hand, provides a decentralized and immutable ledger for transparent and secure transactions. Participants emphasized that these technologies have the potential to revolutionize supply chain management by enhancing traceability, accountability, and efficiency.
3. How do you envision IoT and blockchain technologies enhancing transparency, traceability, and sustainability throughout the supply chain?	When discussing the contribution of IoT and blockchain technologies to enhancing transparency, traceability, and sustainability throughout the supply chain, participants envisioned a scenario where every stage of the supply chain is digitally connected and recorded on a blockchain ledger (Kaliyannan et al., 2023). This would enable stakeholders to track products from source to destination, verify authenticity, and ensure compliance with sustainability standards. They also noted that IoT sensors could monitor environmental conditions and resource usage in real time, allowing for proactive sustainability measures.
4. Based on your experience, what are the critical success factors necessary for effectively	Based on experience, participants identified several critical success factors for effectively implementing IoT and blockchain technologies in supply chain and logistics management to meet sustainability objectives (Shambulingappa & Pavankumar, 2017). These include strong leadership and organizational

implementing IoT and blockchain technologies in supply chain and logistics management to meet sustainability objectives?	commitment, collaboration among participants, investment in technology infrastructure, standardization of data formats and protocols, and establishing clear governance frameworks. Additionally, they emphasized the importance of considering technology adoption's social and ethical implications.
5. What is your understanding of the principles and functionalities of the Internet of Things (IoT) and blockchain technologies, particularly in supply chain sustainability and transparency?	Participants provided examples of how IoT and blockchain technologies have been applied or could be applied to address sustainability and transparency challenges in supply chain management. These include using blockchain to track the provenance of conflict minerals, implementing IoT sensors to monitor temperature-controlled supply chains for food safety, and utilizing smart contracts to ensure fair labor practices in manufacturing (Ghadge et al., 2021). They also discussed the potential for these technologies to enable circular supply chains and reduce waste.
6. From your perspective, what are the potential risks associated with implementing IoT and	When discussing the main barriers to the adoption and integration of IoT and blockchain technologies into existing supply chain frameworks, participants cited concerns about data privacy and security, interoperability among different systems, upfront costs and ROI uncertainty, regulatory

blockchain technologies in supply chain management, and how can these risks be mitigated?	compliance, and resistance to change from traditional practices. They stressed the importance of addressing these barriers through education, pilot projects, industry collaboration, and regulatory support.
7. Can you provide examples of how IoT and blockchain technologies have been applied or could §be applied to address sustainability and transparency challenges in supply chain management?	Participants speculated how adopting IoT and blockchain technologies would impact stakeholder collaboration and communication within the supply chain ecosystem. They argued that these technologies could facilitate greater transparency and trust among stakeholders by providing shared access to accurate and verifiable data. This, in turn, could lead to improved collaboration, faster decision-making, and more effective risk management. However, they also acknowledged the need for clear communication channels and dispute resolution mechanisms to address conflicts of interest.
8. How would adopting IoT and blockchain technologies impact stakeholder collaboration and communication within	When discussing the potential risks associated with implementing IoT and blockchain technologies in supply chain management, participants highlighted concerns about data breaches, cyber-attacks, system failures, and unintended consequences such as increased carbon footprint from technology deployment. They recommended implementing robust cybersecurity measures, conducting regular audits and

the supply chain ecosystem?	vulnerability assessments, ensuring data encryption and access controls, and developing contingency plans for business continuity to mitigate these risks. They also stressed the importance of building trust and transparency with stakeholders through open communication and ethical behavior.
9. What measures or strategies are necessary to ensure the security and integrity of data captured and transmitted through IoT devices and blockchain platforms in supply chain operations?	Participants emphasized the importance of ensuring the security and integrity of data captured and transmitted through IoT devices and blockchain platforms in supply chain operations. They suggested implementing encryption techniques, digital signatures, and access controls to protect data privacy and prevent tampering. Additionally, they recommended conducting thorough due diligence on technology vendors, implementing data governance policies, and providing employees with training on cybersecurity best practices.
10 Based on your insights and expertise, what actionable recommendations and strategies would you	Based on insights and expertise, participants proposed actionable recommendations and strategies for effectively integrating IoT and blockchain technologies into existing supply chain frameworks to promote sustainability and transparency. These include conducting pilot projects to demonstrate

propose for effectively integrating IoT and blockchain technologies into existing supply chain frameworks to promote sustainability and transparency?	feasibility and ROI, collaborating with industry partners and standards bodies to develop interoperable solutions, investing in talent development and training for technology adoption, incentivizing sustainability practices through supply chain incentives, and engaging with regulators to ensure supportive policy frameworks. They also emphasized the importance of continuous monitoring and evaluation to adapt to changing market conditions and technological advancements.

Table 4: Results from interview questions.

4.2. Results from the questionnaire

A questionnaire was used to gather insights on the familiarity, implementation, effectiveness, and challenges of IoT and blockchain technologies in supply chain management. The survey sought to assess perceptions, identify barriers, and evaluate the potential for enhancing transparency and sustainability in supply chain operations. Below are the results from the questionnaire.

Question 1: How familiar are you with the Internet of Things technology?

When asked how familiar they were with IoT technology, most participants (60%) showed a moderate to high familiarity with it, indicating a reasonable level of awareness among the respondents. The table below indicates the participants' responses.

Familiarity level	Number of participants
1: Not at all familiar	1
2: Slightly familiar	1
3: Moderately familiar	3
4: Very familiar	3
5: Extremely familiar	2

Table 5: Participants familiar with IoT technology.

The chart below shows the responses from a percentage point of view.

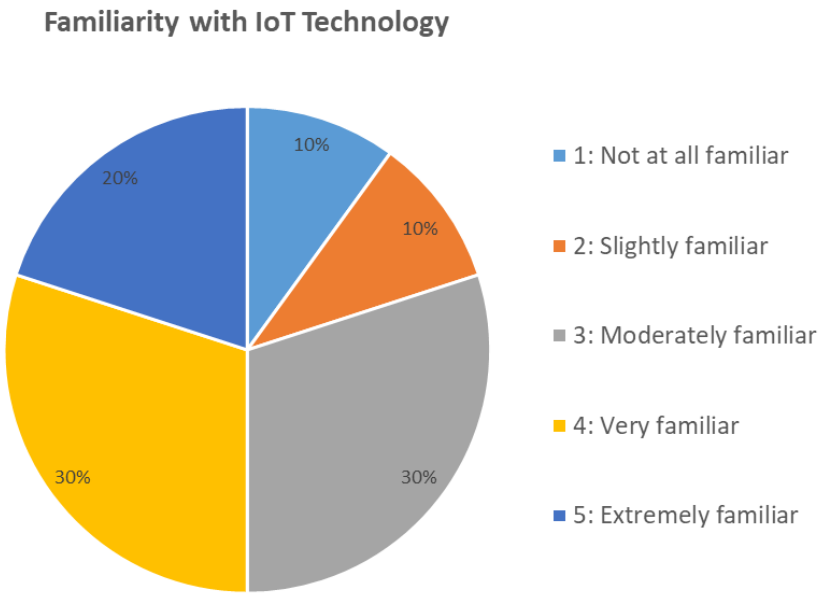

Figure 5: Familiarity with percentages

Question 2: Have you implemented IoT solutions in your supply chain management practices?

The participants were also asked if they had implemented IoT solutions in their supply chains. The figure below shows their responses.

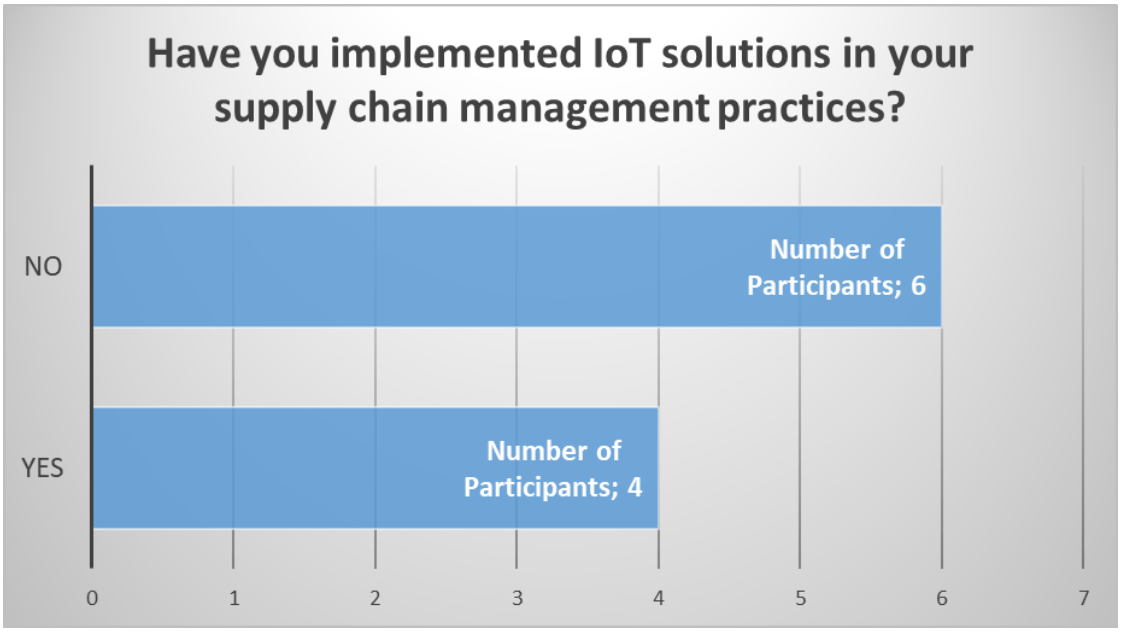

Figure 2: Implementation of IoT solutions in SCM practice.

Most participants (6 out of 10, 60%) had not implemented IoT solutions in their supply chain management, suggesting potential barriers to adoption.

Question 3: How effective do you perceive IoT technology to enhance transparency within supply chain operations?

Effectiveness level	Number of participants	Percentage (%)
1: Not effective at all	0	0%
2: Slightly effective	1	10%
3: Moderately effective	4	40%
4: Very effective	3	30%
5: Extremely effective	2	20%

Table 6: Perceived effectiveness of IoT in promoting transparency.

Explanation: The perception of IoT effectiveness is generally positive, with 70% of participants rating it as moderately to extremely effective.

Question 4: What challenges have you encountered integrating IoT technology into your supply chain processes? (Open-ended)

Explanation: The open-ended responses varied, but common challenges included high costs, technical complexity, and lack of skilled personnel. This indicates areas where support and resources might be needed for better IoT integration.

Question 5: How familiar are you with blockchain technology?

Regarding the participant's familiarity with blockchain, the results indicated that their familiarity with Blockchain technology was slightly lower than IoT, with 40% of participants being at least very familiar. The table below shows the responses from the participants

Familiarity Level	**Number of participants**
1: Not at all familiar	2
2: Slightly familiar	2
3: Moderately familiar	3
4: Very familiar	2
5: Extremely familiar	1

Table 7: Participants familiar with blockchain technology.

The chart below shows the responses from a percentage point of view.

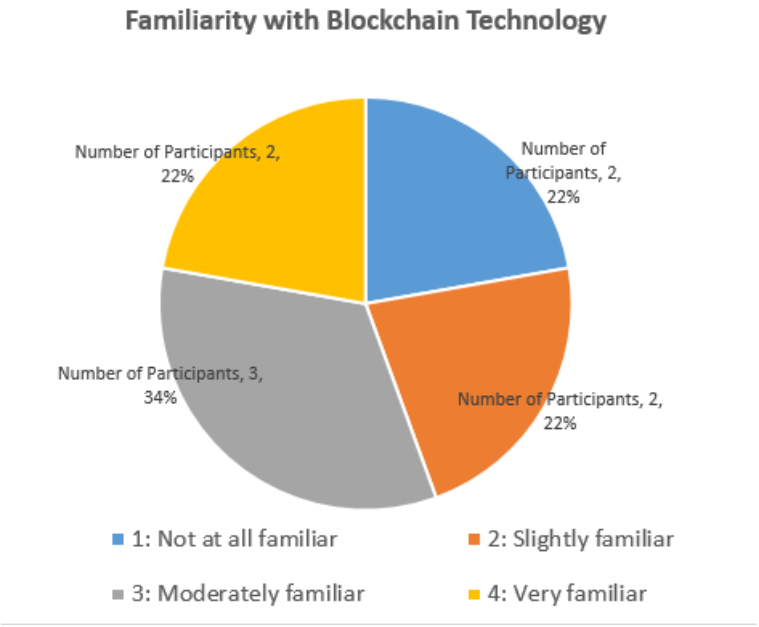

Figure 7: Familiarity of blockchain technology in percentages.

Question 6: Have you implemented blockchain solutions in your supply chain management practices?

Another important question in the questionnaire was whether the participants had implemented blockchain technology solutions in their supply chain. As depicted in the figure below, a significant majority (7 out of 10 participants, 70%) had not implemented blockchain solutions, highlighting a gap in adopting this technology.

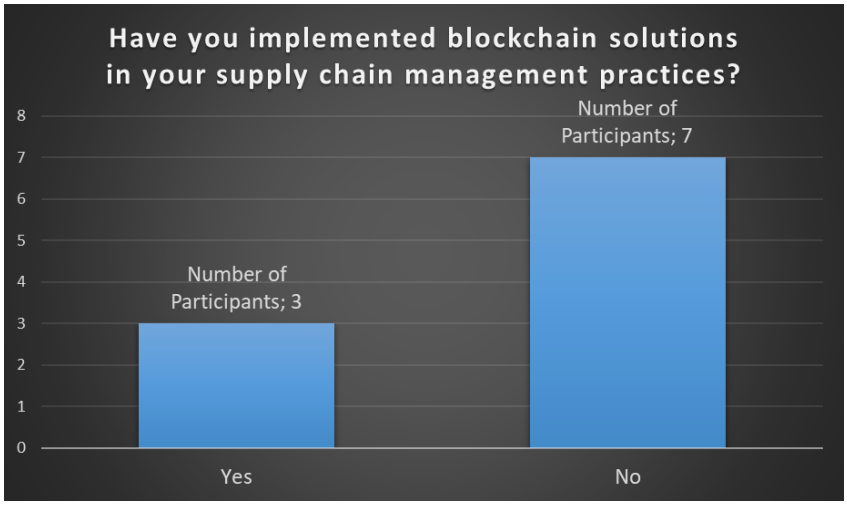

Figure 8: Implementation of blockchain technology in SCM practices.

Question 7: Perception of blockchain's role in enhancing transparency

Participants generally viewed blockchain as a positive tool for enhancing transparency, mentioning its potential for secure, immutable record-keeping. This underscores the technology's perceived benefits.

Question 8: To what extent do you agree with the statement: "Blockchain technology can improve traceability in supply chain management"?

Agreement level	**Number of participants**	**percentage (%)**
1: Strongly disagree	0	0%
2: Disagree	1	10%
3: Neutral	2	20%
4: Agree	4	40%
5: Strongly agree	3	30%

Table 8: How participants agree on the impact of blockchain on traceability.

Explanation: Most participants (70%) agree or strongly agree that blockchain can improve traceability, indicating strong support for its potential impact.

Question 9: What are the main barriers to adopting blockchain technology in supply chain management? (Open-ended)

Explanation: Commonly cited barriers included high costs, regulatory issues, and a lack of understanding or technical expertise. These insights are crucial for addressing challenges to wider adoption.

Question 10: How likely are you to invest in IoT and blockchain technologies for sustainable and transparent supply chain management in the future?

Likelihood level	**Number of participants**	**percentage (%)**
1: Not likely at all	0	0%
2: Somewhat likely	2	20%
3: Moderately likely	3	30%
4: Very likely	3	30%
5: Extremely likely	**2**	**20%**

Table 9: Likelihood of investing in IoT and blockchain for sustainable and transparent SCM.

The likelihood of future investment in IoT and blockchain is high, with 80% of participants at least moderately likely to invest, reflecting optimism about these technologies.

4. Conclusion

This chapter formulates the conclusion and presents the key findings of the research, which were based on interviews and questionnaires. This research was carried out to answer the question: *How do the Internet of Things and blockchain technologies contribute to enhancing sustainability and transparency within supply chain management practices?*

Furthermore, the objectives of the study were:

1. To analyze and identify the challenges and limitations of current supply chain management practices, focusing on sustainability and transparency.
2. To explore the principles and functionalities of the Internet of Things (IoT) and blockchain technologies in supply chain sustainability management to enhance transparency.
3. To explore how IoT and blockchain technologies offer better transparency and tracing of products in supply chain management.
4. To determine the critical success factors crucial for achieving IoT and blockchain implementation successfully in supply chain and logistics management, especially regarding sustainability.
5. To suggest practical recommendations and strategies for seamlessly integrating IoT and blockchain technologies into supply chain frameworks, emphasizing the promotion of sustainability and transparency.

The SCM environment has changed and continues to shift with time. New technologies like the IoT and blockchain technologies are gradually defining the future of SCM initiatives. This research aimed to examine the level of awareness, practice, self-reported success, issues relating to adopting these technologies in SCM, and the contributions of these technologies to SCM transparency and sustainability. Thus, based on the results achieved in this minireview of the questionnaire and the literature review,

the overall conclusions are made for the results obtained and the existing literature, conclusions that outline implications for practice and reveal the prospects for the development of further research.

5.1. Familiarity and adoption rates of IoT and blockchain

The research outcomes show that the IoT generally has moderate to high recognition among the participants, where 60% of them claimed to have moderate to extreme awareness of IoT. The case with blockchain, knowledge of which is slightly less commonplace, with 40% of respondents claiming to be very familiar with the term. However, these technologies adoption and usage are still relatively limited (Hannila, 2023). Regarding other solutions, 40% of the respondents reported implementing IoT solutions in the context of supply chain management, and only 30% reported using blockchain. These statistics imply that despite a seemingly broad knowledge of these solutions, there is still a long way to go regarding the actual uptake.

5.2. Perceived effectiveness in enhancing transparency

IoT and blockchain are perceived positively in terms of their potential to enhance transparency within supply chains. A substantial 70% of participants rated IoT moderately to extremely effective in improving transparency. Similarly, blockchain is viewed favorably, with 70% agreeing or strongly agreeing that it can enhance traceability. These perceptions align with the literature, which underscores the capabilities of IoT in real-time data collection and monitoring and blockchain’s strength in providing secure, immutable records.

5.3. Challenges in implementation

In many situations, specific challenges related to implementing IoT and blockchain technologies are common. Limitations often include high costs, data privacy, technical demands, and the short supply of qualified human resources. Furthermore, regulatory factors and the absence of awareness are other factors implied for the development of blockchain digitalization (Hannila, 2023). They emphasize that more undertakings require assistance in terms of training, finances, and policy stipulations to encourage increased exploitation.

5.4. Implications for sustainable supply chain management

5.4.1. Enhancing transparency and traceability

The findings of this study underscore the auspicious role of IoT and blockchain concepts in improving the levels of sue transparency and traceability across supply chains. IoT allows data acquisition in real-time and constant oversight of things, positively impacting supply chain operations' visibility. Through the ledger fixed in blocks, blockchain assures the integrity of all the operations executed to minimize fraud and establish stakeholder credibility (Queiroz et al., 2020).

5.4.2. Supporting sustainable practices

Integrating IoT and blockchain technologies is also helpful in creating sustainable supply chain management mechanisms. IoT enables tracking environmental stimuli and

resources to be utilized effectively and wisely. The integration can also offer assurance as to the origin of the material and the product, which may help companies to ensure that they are sourcing sustainably. They keep track of the information that enables management to support the organizational change and prove the successful implementation of sustainable practices (Jondhale et al., 2022).

5.5. Future directions and recommendations

5.5.1. Addressing adoption barriers

To overcome barriers to adoption, adequately applying the strategies corresponding to the mentioned challenges is necessary. The right talent must be recruited and managed effectively, implying investments in education and training to acquire technical know-how. Ben-Daya et al. (2019) have indicated that high cost is another factor that has been said to hinder technology implementation; however, other words like subsidies or tax reductions might help to ease the high costs. In addition, clear regulations and guidelines are essential for organizations adopting blockchain solutions.

5.5.2. Enhancing collaboration and standardization

This study shows that achieving the potential of IoT and blockchain applications in supply chains requires collective efforts and contributions from industry players, technology solution providers, and other regulatory bodies (Jondhale et al., 2022). Adopting protocols and interface standards helps in systems integration and improves the efficiency and effectiveness of these technologies. They can also enhance the development of shared and improved processes across the industry, which translates to improved solutions and innovations.

5.6. Conclusion

This study shows that IoT and blockchain technologies are valuable tools for increasing transparency, enhancing traceability, and ultimately improving sustainability in supply chain management. Still, the challenges in implementing the strategy are enormous; however, the participants' positive attitude and future investment intentions, especially in sectors like finance and logistics, offer a measure of optimism. The critical barriers highlighted above must be effectively addressed to enhance the incorporation of innovative technologies in the supply chain that can increase efficiency and transparency.

Further studies should concentrate on creating financial incentives and specialized training to overcome adoption barriers like high cost, data privacy, and skill gaps. The research should identify practical applications for dealing with the challenges, best practices, and real-world advantages of applying IoT and blockchains for sustainable and transparent SCM. Furthermore, the industry stakeholders' collaboration and standardized practices can improve interoperability.

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Appendix

Questionnaire

1. On a scale of 1 to 5, how familiar are you with Internet of Things (IoT) technology?

    1: Not at all familiar

    2: Slightly familiar

    3: Moderately familiar

    4: Very familiar

    5: Extremely familiar

2. Have you implemented IoT solutions in your supply chain management practices?

    1. Yes
    2. No

3. On a scale of 1 to 5, how effective do you perceive IoT technology to enhance transparency within supply chain operations?

1: Not effective at all

2: Slightly effective

3: Moderately effective

4: Very effective

5: Extremely effective

4. What challenges have you encountered integrating IoT technology into your supply chain processes? (Open-ended)

5. On a scale of 1 to 5, how familiar are you with blockchain technology?

1: Not at all familiar

2: Slightly familiar

3: Moderately familiar

4: Very familiar

5: Extremely familiar

6. Have you implemented blockchain solutions in your supply chain management practices?
    1. Yes
    2. No

7. How do you perceive the role of blockchain in enhancing supply chain transparency? (Open-ended)

8. To what extent do you agree with the statement: "Blockchain technology can improve traceability in supply chain management"?
    1. Strongly disagree
    2. Disagree
    3. Neutral

4. Agree
5. Strongly agree

9. What are the main barriers to adopting blockchain technology in supply chain management? (Open-ended)

10. How likely are you to invest in IoT and blockchain technologies for sustainable and transparent supply chain management in the future?
    1. Not likely at all
    2. Somewhat likely
    3. Moderately likely
    4. Very likely
    5. Extremely likely

Interview Questions

1. Can you describe the current challenges and limitations you encounter in supply chain management practices concerning sustainability and transparency?

2. What are the main barriers or obstacles you foresee in adopting and integrating IoT and blockchain technologies into existing supply chain frameworks?

3. How do you envision IoT and blockchain technologies enhancing transparency, traceability, and sustainability throughout the supply chain?

4. Based on your experience, what are the critical success factors necessary for effectively implementing IoT and blockchain technologies in supply chain and logistics management to meet sustainability objectives?

5. What is your understanding of the principles and functionalities of the Internet of Things (IoT) and blockchain technologies, particularly in supply chain sustainability and transparency?

6. From your perspective, what are the potential risks associated with implementing IoT and blockchain technologies in supply chain management, and how can these risks be mitigated?

7. Can you provide examples of how IoT and blockchain technologies have been applied or could be used to address sustainability and transparency challenges in supply chain management?

8. How would adopting IoT and blockchain technologies impact stakeholder collaboration and communication within the supply chain ecosystem?

9. What measures or strategies are necessary to ensure the security and integrity of data captured and transmitted through IoT devices and blockchain platforms in supply chain operations?

10. Based on your insights and expertise, what actionable recommendations and strategies would you propose for effectively integrating IoT and blockchain technologies into existing supply chain frameworks to promote sustainability and transparency?