Blockchain Technology in Supply Chain Management

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Admission No: 23GSOB2040017

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MBA 2023 – 2025

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ABSTRACT

The growing complexity and globalization of supply chains have increased the demand for enhanced transparency, traceability, and security in supply chain operations. Traditional supply chain systems often suffer from issues such as data silos, lack of real-time visibility, and vulnerability to fraud and counterfeiting. In this context, blockchain technology has emerged as a transformative solution with the potential to revolutionize supply chain management (SCM). This study explores the integration of blockchain technology into supply chain systems, with a particular focus on its role in improving transparency, efficiency, and trust among stakeholders.

The research examines the core features of blockchain—such as decentralization, immutability, and smart contracts—and analyzes their applications in various supply chain sectors including manufacturing, agriculture, pharmaceuticals, and logistics. Through a combination of literature review and primary data collection via surveys, the study assesses the awareness, adoption levels, perceived benefits, and key challenges associated with blockchain implementation in supply chains.

Findings indicate that while the adoption of blockchain is still at an early stage for many organizations, there is a strong recognition of its potential to enhance traceability, reduce fraud, and streamline operations. However, barriers such as high implementation costs, lack of technical expertise, and integration with legacy systems remain significant concerns. The study concludes by highlighting strategic recommendations for organizations considering blockchain adoption and emphasizes the need for collaborative efforts, regulatory clarity, and further research to unlock the full potential of blockchain in supply chain management.

INTRODUCTION

Block Chain has recently gained importance as a promising technology in the area of supply chain management. For instance, Maersk used an IBM blockchain solution to efficiently track its containers around the world. Blockchain technology is a decentralised digital ledger that records transactions in a secure and transparent manner. It was first introduced in 2008 as the backbone of Bitcoin, but has since expanded to a wide range of applications.

The blockchain consists of blocks, which are linked together in chronological order to form a chain. Each block contains a set of transactions that have been verified by network participants known as nodes. Once a block is added to the chain, it cannot be altered or deleted.

One of the key features of blockchain technology is its decentralisation. Unlike traditional databases, which are typically controlled by a single entity, blockchain allows for multiple parties to participate in the network and verify transactions. This means that there is no central point of control and no single point of failure.

Indeed, blockchain is a distributed ledger (database) through which supply chain partners can interact and create, verify, validate, and securely store various kinds of records such as product information, certificates, localization data, transaction records, data acquired from sensors and other connected devices.

Thus, in addition to providing traceability and making the whole history of products digitally available, blockchain promises to improve supply chain coordination and process efficiency and to achieve supply chain sustainability goals .Blockchain technology has transformed the business world, and supply chain management is no exception. With its ability to create secure and transparent networks, blockchain will reshape the way we manage supply chains. And it has already started.

Therefore, a lot of time, money and energy is put here, and a multitude of that money is expected for the industry in the future: According to a comprehensive research report by Market Research Future (MRFR), the market is expected to grow significantly to reach a value of around USD 17.15 billion by the end of 2030.
In recent years, supply chain management has become increasingly complex. Globalisation and advances in technology have made it possible for companies to operate across borders and collaborate with suppliers and partners from all over the world. One of the biggest challenges facing supply chain managers today is maintaining visibility across the entire network. As goods move from one location to another, it can be difficult to track them accurately. This lack of transparency can lead to delays, errors, and even fraud. By creating a secure and transparent network that allows for real-time tracking of goods at every stage of the supply chain, blockchain technology can help address many of these challenges. It provides a tamper-proof ledger that ensures data integrity while enabling all parties on the network to access information in real-time.

In this report, we will explore how blockchain technology can help improve transparency, traceability, and efficiency across the entire supply chain. We will examine different use cases for blockchain in supply chain management and highlight best practices for successful implementation. Finally, we will look ahead to the future and examine how blockchain technology is likely to transform supply chain management over the coming years.Blockchain technology is a decentralised digital ledger that records transactions in a secure and transparent manner. It was first introduced in 2008 as the backbone of Bitcoin, but has since expanded to a wide range of applications.

The blockchain consists of blocks, which are linked together in chronological order to form a chain. Each block contains a set of transactions that have been verified by network participants known as nodes. Once a block is added to the chain, it cannot be altered or deleted.Our paper provides both theoretical and practical contributions that improve our understanding of the enablers of blockchain adoption in supply chains and offer guidance to managers and policymakers on how they can best direct their efforts to enhance adoption. From the theory perspective, our work is the first effort to provide an extensive list of enabling factors of blockchain adoption in supply chains, evaluate their effects and map their interdependencies.

It also adds contribution to the very limited body of research that uses a multi-theoretic framework to establish the theoretical context of blockchain technology adoption for the supply chain management. Our study also contributes to the practice by providing an evaluation of the importance of the enablers of blockchain adoption in the supply chain and by analyzing their interdependencies. Managers and policymakers may use the results and insights from this study to inform their decisions and action plans for blockchain adoption in their supply chains.

Benefits of Implementing Blockchain in Supply Chain Management

Implementing blockchain technology in supply chain management can provide a range of benefits, including:

Improved Traceability, Transparency and Trust

The key quality of the blockchain is the transparent and immutable record of all transactions within the supply chain. This facilitates the tracing of products from their origin to their destination, improves accountability and reduces the risk of fraud. This also provides greater transparency within the supply chain and allows companies to track products and monitor performance in real time. This in turn can also improve trust between partners within the supply chain.

Increased Efficiency leads to speed

By automating many processes within the supply chain, blockchain technology can increase efficiency and reduce costs. This could include automating payments, tracking inventory levels, or streamlining logistics processes. And it paves way for another critical component: the need for speed.

Reduced Costs

Implementing blockchain technology can help reduce costs across the entire supply chain by eliminating intermediaries and reducing administrative overheads. That starts in the development and planning phase and stretches to making, delivering and also returning products.
For example, the automotive industry can save costs through reducing the cost of inventory tracking. Currently, tracking inventory levels involves manual tasks such as checking for stock availability and manually updating records. By leveraging blockchain, companies can automate these processes and reduce the administrative overheads associated with them.

Enhanced Security by Immutability

Blockchain technology is highly secure due to its distributed nature and use of cryptography. Immutability is one of the key features of blockchain technology. By using distributed ledgers and cryptographic techniques, data stored on a blockchain can be permanently secured and remain unchanged over time. This makes it virtually impossible for malicious actors to tamper with data on the blockchain or alter the history of transactions.

Better Customer Experience

Also the customers benefit from the use of the blockchain in SCM, because businesses are able to deliver products faster and more accurately. Additionally, blockchain's transparent nature allows customers to trace the origins of their products and track them through the supply chain. This helps build customer trust in businesses as they can see exactly where their product is and know that the product is authentic and has been sourced responsibly. Sustainability is a key factor in this decade, for consumers and business alike.

Traceability and Transparency

One of the biggest challenges for supply chain management executives is maintaining visibility across the network. Blockchain technology can help address this challenge by providing a secure and transparent way to track goods as they move through the supply chain. This can help reduce the problems already mentioned while improving efficiency, security and the shopping experience for businesses, wholesalers, retailers and ultimately consumers.

Environmental and Ethical Sustainability

As sustainability and ESG aspects become more important in our world, blockchain technology will be used to promote environmental sustainability by tracking carbon emissions and other environmental impacts throughout the supply chain. This information can then be used to identify areas for improvement and reduce overall environmental impact. In addition, blockchain technology can help companies ensure that their products are ethically sourced. By tracking products from the point of origin, businesses can identify and flag any potential ethical issues such as child or slave labour, fair wages or safe working environments in the supply chain.

Future Outlook: How Will Blockchain Transform the Future of Supply Chain Management?

Blockchain technology has already begun to transform supply chain management, but its impact is only just beginning. Here are some projections of how blockchain will play into supply chain management in the future. Also take a look at Fig. 2 "Strategic business value of Blockchain" for more insights.

Greater Adoption

As more businesses recognise the benefits of blockchain technology, we can expect to see greater adoption across the entire supply chain. This will create a more interconnected and efficient ecosystem that benefits everyone involved.

Increased Integration with IoT

Talking about an interconnected ecosystem, the Internet of Things (IoT) is already being used in many supply chains to track products and monitor performance. By combining it with blockchain technology, IoT devices can provide even greater transparency and traceability within the supply chain.

Improved Sustainability

Europe will soon have mandatory reporting on environmental, social and governance (ESG) issues. On Dezember 16, 2022, the European Parliament adopted the EU Corporate Sustainability Reporting Directive. Using the directive, the EU is aiming for a uniform and binding framework that will end greenwashing and strengthen the social market economy. In the future, companies will have to give more information about the social and environmental effects of their actions. Therefore, blockchain technology will help improve sustainability within the supply chain by making it easier to track and verify sustainable practices such as fair trade and wages or ethical practices.

Emergence of New Business Models

As blockchain technology continues to evolve, we may see entirely new business models emerge within the supply chain that take advantage of its unique capabilities. Food safety is one example of a new business model. The IBM Food Trust platform uses blockchain technology to enhance transparency and traceability in the food supply chain. It enables food producers, processors, distributors, and retailers to track and share information about the origin, quality, and safety of food products. In this way, contaminated or unsafe products can be quickly and accurately identified and sorted out, reducing the risk of foodborne illness and minimising the impact of food recalls.

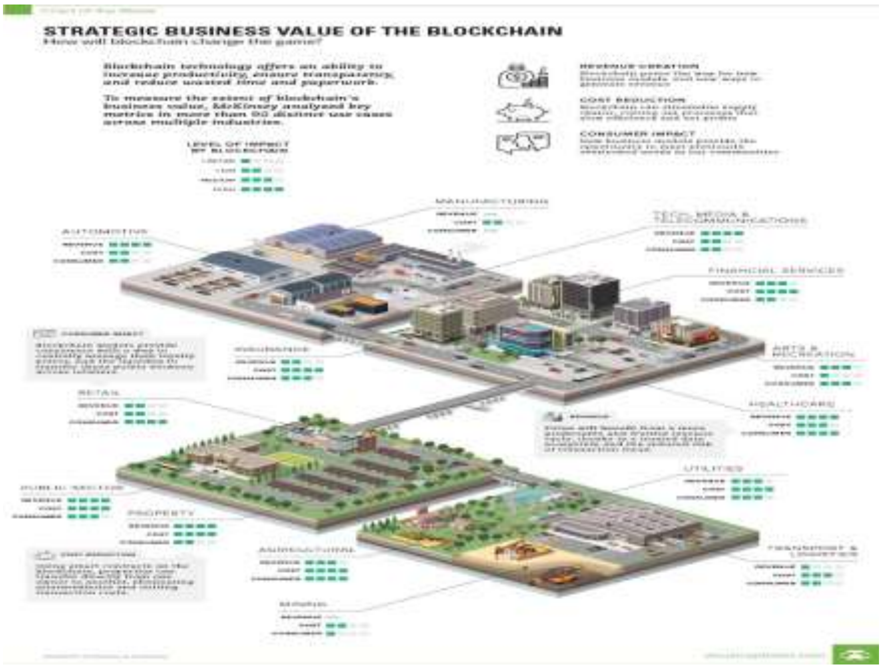


Figure 2: Strategic Business Value of Blockchain

BACKGROUND

In recent decades, globalization and digital transformation have significantly reshaped the landscape of supply chain management (SCM). Supply chains have become increasingly complex, involving multiple stakeholders, cross-border transactions, and a growing demand for transparency, traceability, and ethical practices. As consumer awareness and regulatory pressure increase, the ability to ensure authenticity, safety, and compliance throughout the supply chain has become a strategic priority for businesses.Simultaneously, technological advancements have introduced new tools to address long-standing challenges in SCM. Among these, blockchain technology has emerged as a potentially transformative solution due to its ability to offer secure, transparent, and immutable records of transactions and product movements.

In supply chain management, blockchain can facilitate end-to-end visibility of products, from raw materials to end consumers. By recording each step of the product lifecycle on an immutable ledger, blockchain helps ensure accountability, reduce fraud, enhance efficiency, and support sustainability goals. For example, consumers can scan a QR code on a food item or clothing tag to trace its origin, manufacturing process, and journey through the supply chain.This thesis explores the intersection of blockchain technology and supply chain transparency, aiming to understand how this innovative technology can reshape traditional supply chains and meet the growing demand for openness and accountability.

Use of blockchain technology in supply chain management

A supply chain is typically composed of independent organizations which are directly involved in the upstream and downstream flows of products, services, finances, and/or information from a source to a customer . Effective management of a supply chain requires members to cooperate and mutually share information . In this regard, blockchain technology promises to drastically improve supply chain management and achieve supply chain performance objectives by providing a platform for direct interaction between supply chain members to exchange credible and tamper-proof data .

One of the main benefits of this technology is that it enables full product traceability and enhances visibility through the different supply chain stages . For instance, using smart tagging and blockchain technology, the UK-based blockchain solutions provider Provenance was able to successfully track fish caught by fishermen in Indonesia, and provide robust proof of compliance to standards from the origin and along the chain to consumers . Another example of blockchain-enabled product tracking is the pilot project conducted by Walmart in collaboration with IBM to digitally track pork products in China from the farm to the customer table. The technology enabled timely digital access to full individual pork product data, including the farm it comes from, factory it went through, the batch number, the storage temperature and shipping details

Adoption of blockchain technology in the supply chain

The innovative nature of blockchain technology and its potential for improving supply chain management has woken the interest in investigating the challenges and enablers of its adoption in supply chain contextThus, to further encourage blockchain adoption in global supply chains, the authors advocate agreeing on standards and rules for interoperability between blockchains, as well as adapting current regulations and industry practices to the new dematerialized, automated and global nature of blockchains. Drawing on in-depth interviews with supply chain experts, reported on the perceived challenging nature of the complexity of the technology and its high cost of implementation.

In a study involving four supply chains in the dairy food sector, identified 18 boundary conditions for using blockchain solutions to provide product traceability. These conditions were then aggregated in 5 categories which are: firm's internal business processes and information system-related conditions such as the technical capacity and ability of different supply chain members to maintain traceability; supply chain process conditions that involve the interface and consistency between internal and external supply chain-related processes; traceability conditions that comprise consensus between supply chain members on the type, level of details and granularity of traceability data; quality-related conditions that involve consistency between supply chain members with regards to quality data; and regulatory conditions in relation with compliance to different product, country or customer-specific regulations.

The above works are mostly oriented towards identifying impediments and challenges of blockchain technology implementation in supply chains. Adopting a different perspective, examined the enabling factors of blockchain adoption for traceability in agriculture supply chain and highlighted the positive influence of the blockchain-enabled reduction of transaction cost, information sharing and data security.

In a study of the organizational enablers of blockchain adoption in supply chains, found that top management support and organizational readiness are significant determinants of blockchain adoption, and large companies are more likely to adopt blockchain than small to medium-sized enterprises (SMEs). Using the TOE framework and survey results, find that blockchain complexity, cost and relative advantage have significant effects on the intention to adopt blockchain technology for supply chain management in Malaysian SMEs. In our study, we adopt a comprehensive approach and use elements from all the above studies to build an extended list of blockchain adoption enablers in the supply chain.

While each method has its advantages and limits, ours allows for capturing and analyzing the direct mutual influences among all the enablers. Lastly, our analysis is focused on getting insights from practitioners in different industries and sectors, while a major part of the work in is dedicated to comparing results from academics with those obtained from practitioners. Given these differences with existing literature, our study adds new results and insights.

PROBLEM STATEMENT

Traditional supply chains often suffer from data silos, lack of trust, and information asymmetry. This thesis investigates how blockchain can provide a secure and transparent framework for supply chain stakeholders.

Research Objectives

- To understand the fundamentals of blockchain technology
- To explore its application in improving supply chain transparency
- To evaluate the benefits and limitations of blockchain in real-world scenarios

Research Questions

- How does blockchain enhance supply chain transparency?
- What are the challenges in implementing blockchain in SCM?
- What industries benefit the most from blockchain adoption?

Scope and Limitations

- Focus on key industries: food, pharmaceuticals, fashion, and electronics. Limited by available case studies and stakeholder access.

LITERATURE REVIEW

History and Evolution of Blockchain

1. Early Concepts and Origins (1990s – 2008)

The foundational ideas behind blockchain technology emerged in the early 1990s when computer scientists Stuart Haber and W. Scott Stornetta introduced a cryptographically secure chain of blocks to timestamp digital documents, ensuring they could not be backdated or tampered with. In 1992, they incorporated Merkle trees into the design to improve efficiency, allowing for the collection of multiple documents into a single block.

However, the modern concept of blockchain was truly realized in 2008, when the pseudonymous figure Satoshi Nakamoto published the white paper titled "Bitcoin: A Peer-to-Peer Electronic Cash System." In this paper, Nakamoto introduced a decentralized, trustless digital currency that did not rely on central banks or financial institutions. The core innovation was the blockchain—a distributed ledger that records all transactions across a peer-to-peer network.

2. Blockchain 1.0: Cryptocurrency and Bitcoin (2009 – 2013)

In January 2009, Nakamoto launched the Bitcoin network by mining the first block, known as the Genesis Block. This marked the beginning of Blockchain 1.0, which primarily focused on supporting cryptocurrencies. The blockchain was used solely for recording Bitcoin transactions, enabling secure and transparent value transfer without intermediaries.
Bitcoin demonstrated the first real-world application of blockchain, offering immutability, decentralization, and cryptographic security. However, its functionality was limited to financial transactions.

3. Blockchain 2.0: Smart Contracts and Ethereum (2014 – 2017)

The next major evolution came with Blockchain 2.0, which extended the capabilities of blockchain beyond digital currency. In 2015, the Ethereum platform was launched by Vitalik Buterin and others, introducing smart contracts—self-executing contracts with the terms of the agreement directly written into code.

Ethereum enabled decentralized applications (dApps), fostering innovation across industries such as finance, gaming, identity, and supply chain. Blockchain became programmable, allowing for the development of decentralized ecosystems.

4. Blockchain 3.0: Enterprise Adoption and Scalability (2018 – Present)

Blockchain 3.0 focuses on enterprise-level applications, interoperability, and scalability. During this period, private and consortium blockchains like Hyperledger Fabric, R3 Corda, and Quorum emerged, offering more control, speed, and privacy suited for business environments.

Major companies such as IBM, Walmart, Maersk, and Nestlé began exploring blockchain for supply chain transparency, traceability, compliance, and anti-counterfeiting. Initiatives like IBM Food Trust, TradeLens, and MediLedger illustrated blockchain's potential to solve complex supply chain issues.

Additionally, efforts to address blockchain's limitations—such as high energy consumption, transaction speed, and governance—led to new consensus mechanisms (e.g., Proof of Stake), layer-2 solutions, and hybrid architectures.

5. Emerging Trends and Future Outlook

The future of blockchain is being shaped by:

- Integration with other technologies like Internet of Things (IoT), Artificial Intelligence (AI), and cloud computing

- Sustainability improvements through energy-efficient consensus mechanisms
- Government and regulatory involvement in digital identity, CBDCs (Central Bank Digita Currencies), and trade
- Decentralized Finance (DeFi) and Web3 models for peer-to-peer value exchange

While still evolving, blockchain is transitioning from a disruptive concept to a core element in digital transformation strategies, especially in enhancing supply chain visibility, security, and efficiency.

Comparative analysis of traditional vs. blockchain based SCM systems

Traditional and blockchain-based supply chain management systems differ significantly in their approach to data management, security, and transparency. Traditional systems often rely on centralized databases and manual processes, leading to potential issues with data integrity, transparency, and collaboration. Blockchain, on the other hand, offers a decentralized, immutable, and transparent ledger, enhancing security and traceability.

Here's a more detailed comparison:

Comparision factor	Traditional SCM	Blockchain SCM
Data Management	Centralized databases managed by a single entity, making them vulnerable to data tampering and security breaches.	Decentralized, distributed ledger, where data is shared and verified across multiple participants, enhancing security and data integrity
Transparency and Traceability	Limited transparency and visibility throughout the supply chain, making it difficult to track the origin, movement, and condition of goods.	Enhanced transparency and traceability, as every transaction is recorded on the blockchain and accessible to all authorized participants
Security	Vulnerable to cyber threats, data breaches, and counterfeiting due to centralized control and lack of robust security	Offers inherent security through cryptographic techniques and decentralized consensus mechanisms, making

	measures.	it more resistant to tampering and fraud.
Collaboration and Interoperability	Can suffer from data silos and lack of interoperability between different systems, hindering collaboration among supply chain partners.	Facilitates seamless collaboration and data sharing among participants, fostering trust and streamlining processes.
Scalability	**:**MMay struggle to scale and adapt changing market conditions, particularly in nplex supply chains.	Offers scalability and adaptability, allowing businesses to expand their operations and handle increasing transaction volumes.
Cost	May incur significant costs associated with maintaining centralized infrastructure, security measures, and manual processes.	**Bl**Can potentially uce costs by streamlining cesses, reducing errors, and ninating intinterermediaries.

OVERVIEW- BLOCKCHAIN TECHNOLOGY

Structure of Blockchain
Blocks:Each block contains a set of transactions, a timestamp, and a cryptographic hash of the previous block, ensuring data integrity and a chronological order.

Chain:Blocks are linked together sequentially, forming a chain where each block's hash references the previous block, creating an immutable record.

Data:Blocks can store various data, including transactions, smart contract details, and other relevant information.

Nodes:The blockchain network consists of numerous nodes, each storing a copy of the ledger. These nodes participate in verifying transactions and adding new blocks to the chain.

Consensus Mechanism:A mechanism, such as Proof-of-Work (PoW) or Proof-of-Stake (PoS), is used to validate transactions and agree on the next block to be added to the chain, ensuring data integrity and security.
Types of Blockchain

1. **Public Blockchain**

Definition: A public blockchain is a completely decentralized and open network that anyone can join, read, write, or participate in. All transactions are visible to all participants, and the ledger is maintained by a distributed network of nodes.

Examples:
Bitcoin
Ethereum

Use Cases in SCM:
Enhancing consumer trust through full supply chain transparency
Public product traceability (e.g., organic food origin tracking)

Limitations:
Slower transaction speed
Higher energy consumption

Lack of data privacy

2. Private Blockchain

Definition: A private blockchain is a permissioned blockchain controlled by a single organization. Only authorized users can participate, access data, or validate transactions.

Examples:
Hyperledger Fabric
R3 Corda

Use Cases in SCM:
Internal supply chain optimization
Confidential contract enforcement between known parties
Regulatory compliance and audit trails

Limitations:
Reduced decentralization
Trust depends on central authority

3. Consortium (Federated) Blockchain

Definition: A consortium blockchain is governed by a group of organizations, rather than a single entity. Access is granted only to selected participants, making it semi-decentralized.

Examples:
IBM Food Trust (Walmart, Nestlé, Dole, etc.)
TradeLens (Maersk and IBM)
MediLedger (pharmaceutical supply chains)

Use Cases in SCM:
Cross-company logistics and inventory tracking
Multi-party supplier networks
Shared compliance reporting and certification

Limitations:
Requires collaboration and trust between members
Can be complex to manage governance rules

4. Hybrid Blockchain

Definition: A hybrid blockchain combines features of both public and private blockchains. Some data is public and visible to all, while other data is restricted to authorized participants.

Examples:
XinFin (hybrid blockchain for global trade and finance)

Use Cases in SCM:
Sharing selected product information with end-users while protecting sensitive business data
Public certifications (like sustainability labels) with private internal process management

Limitations:
Complexity in design and integration
Risk of conflicting objectives between public and private components.

CASE STUDIES

Case Study: IBM Food Trust & Walmart

Overview: In 2018, Walmart partnered with IBM to leverage blockchain technology through the **IBM Food Trust** platform to enhance traceability and transparency across its food supply chain. This initiative aimed to improve food safety, reduce waste, and increase consumer confidence in food sourcing.

The Challenge

1. Food Safety Concerns

- The food industry regularly faces outbreaks (e.g., E. coli in romaine lettuce).
- Tracing contaminated food back to the source traditionally took days or even weeks.
- During that time, retailers would pull large quantities of products from shelves, leading to waste and loss of consumer trust.

2. Supply Chain Complexity

- Walmart's supply chain spans multiple countries and suppliers.
- The traditional record-keeping system relied on paper-based logs and siloed digital records, making traceability slow and unreliable.

3. Consumer Demand for Transparency

- Consumers increasingly demand knowledge about the origin, journey, and ethical sourcing of food products.

The Solution: IBM Food Trust

About IBM Food Trust

- A **blockchain-based platform** developed by IBM.
- Allows participants (growers, processors, distributors, retailers) to input and access data across the supply chain in **real time**.
- Offers **immutability, transparency, and security** of data.

Implementation with Walmart

- Walmart mandated that all leafy greens suppliers join IBM Food Trust.
- The goal was to ensure traceability of products like romaine lettuce and spinach from farm to store in 2.2 seconds, compared to 7+ days previously.

How It Works

1. Blockchain Integration

- Each node in the supply chain logs data (e.g., harvest date, processing facility, shipping data).
- Data is **timestamped and stored** immutably on the blockchain.

2. Supplier Participation

- Suppliers were onboarded with support from IBM and Walmart.
- Each was required to digitize traceability records.

3. Data Accessibility

- Walmart could trace a specific product's origin quickly using a mobile app or dashboard.
- This enabled **fast recalls** and **targeted actions** in case of contamination.

Key Results & Benefits

1. Time Reduction in Traceability

- Reduced the time to trace the origin of a product from 7 days to 2.2 seconds**.**

2. Enhanced Food Safety

- Walmart could **quickly identify and isolate** affected products in an outbreak, preventing wider recalls and protecting consumers.

3. Improved Supply Chain Efficiency

- Digitization removed the need for manual, paper-based processes.
- Enabled faster audits**,** better inventory management**,** and reduced waste.

4. Strengthened Supplier Relationships

- Smaller suppliers became part of a shared digital ecosystem, increasing their visibility and performance monitoring.

5. Consumer Trust

- Consumers gained more confidence in the origin and safety of their food, enhancing Walmart's brand image.

Challenges Faced

1. Onboarding Suppliers

- Many small-scale farmers lacked digital infrastructure.
- IBM and Walmart had to provide **training and support**.

2. Data Standardization

- Data came in various formats from different entities.
- A consistent structure for data entry and transmission was necessary.

3. Initial Investment Costs

- Blockchain integration required **investment in hardware, software, and training**, which some suppliers were hesitant to bear.

Technological Highlights

- **Blockchain Type:** Permissioned (Hyperledger Fabric)
- **Data Points Tracked:** Harvesting, processing, packaging, distribution, store arrival
- **Participants:** Farmers, processors, logistics providers, retailers

Impact on the Industry

- **Set a precedent** for traceability in food retail.
- Inspired competitors (e.g., Carrefour, Nestlé, Unilever) to explore blockchain for food traceability.
- Encouraged **regulatory bodies** to consider digital traceability standards.

Key Takeaways

Category	**Outcome**
Traceability Time	Reduced from 7 days to 2.2 seconds
Food Safety	Faster response in recalls and contamination events
Efficiency	Automated data logging and sharing
Supplier Inclusion	Broad digital participation, even from small farms
Consumer Confidence	Greater transparency and trust

Conclusion: The Walmart-IBM Food Trust collaboration marked a turning point in the **digitization of the food supply chain**. By adopting blockchain, Walmart not only enhanced its operational efficiency and food safety but also paved the way for an industry-wide transformation in how food is tracked and trusted.

Case Study: MediLedger – Transforming the Pharmaceutical Supply Chain with Blockchain

Overview

The **MediLedger Project** is a blockchain-based initiative aimed at combating counterfeit drugs, improving supply chain visibility, and ensuring compliance with regulatory mandates like the **U.S. Drug Supply Chain Security Act (DSCSA)**. It brings together major pharmaceutical companies and distributors to build an **interoperable, decentralized network** for tracking and verifying prescription medicines.

Industry Context

The Problem of Counterfeit Drugs

- The **World Health Organization (WHO)** estimates that **1 in 10 medical products** in low- and middle-income countries is substandard or falsified.
- In the U.S., although stricter controls exist, **counterfeit drugs can still enter** the supply chain, particularly during distribution.

Regulatory Pressure: DSCSA

- The **DSCSA (2013)** mandates full electronic, interoperable tracking of prescription drugs at the **package level** by **2024**.
- Requires serialization, verification of returns, and authorized trading partner (ATP) compliance.

The MediLedger Project

Background

- Initiated in 2017 by **Chronicled**, a blockchain startup based in San Francisco.
- Formed a consortium of **leading pharma companies**: Pfizer, Gilead, Amgen, Genentech, AmerisourceBergen, Cardinal Health, and others.
- Built using **Hyperledger and Ethereum** frameworks to create a **permissioned blockchain network**.

Key Challenges in Pharma Supply Chain

1. Lack of Interoperability

- Multiple systems across companies led to data silos and inefficiencies.
- No standard, secure way to share sensitive information across firms.

2. Counterfeit Risks

- Fake or diverted drugs could enter the supply chain due to gaps in verification and tracking**.**

3. Verification of Returns

- $6–10 billion in pharmaceuticals are returned annually in the U.S.
- Distributors need to verify saleable returns within 24 hours under DSCSA.

4. Trust Issues Among Competitors

- Pharma firms are competitors with **little incentive to trust each other's data** without a neutral system.

MediLedger's Solution

1. Blockchain-Based DSCSA Compliance

- A decentralized network where no single entity owns the data**.**
- Enables peer-to-peer verification of drug identifiers and authorized trading partners.

2. Product Verification Solution

- Enables wholesalers to verify the **legitimacy of returned drugs** using the manufacturer's database via the blockchain.
- Returns can be verified instantly, even if the systems aren't directly integrated.

3. Authorized Trading Partner (ATP) Network

- Establishes a permissioned registry for verifying if a trading partner is authorized under DSCSA.

4. Interoperability Framework

- MediLedger's system **does not store product data on-chain**.
- Instead, it uses the blockchain to **validate cryptographic proofs and permissions** while allowing off-chain data exchange.

Technology Stack

Component	**Description**
Blockchain	Ethereum-based with zero-knowledge proofs, Hyperledger elements
Data Privacy	Zero-Knowledge Proofs (ZKPs), ensuring companies share only necessary info
Network Type	Permissioned consortium blockchain
Smart Contracts	Used to verify data integrity and business rules
APIs	Standardized REST APIs for easy integration with existing systems

Implementation Timeline

Year Milestone

2017 Project launched by Chronicled

2018 First working group for DSCSA verification of returns

2019 Launch of live product verification network

2020 ATP solution released for industry-wide compliance

2021–23 Expansion into broader interoperability frameworks for full DSCSA 2024 readiness

Results & Impact

1. Regulatory Compliance

- **Fully DSCSA-compliant** for product verification and ATP compliance.
- Manufacturers and wholesalers can verify product authenticity and ATP status **instantly**.

2. Faster Verification of Returns

- Verification time reduced from **days to seconds**.
- Prevents **unnecessary destruction** of legitimate returned drugs, saving billions.

3. Industry Collaboration

- Established trust among competitors by **neutralizing data control**.
- Over 20 major players in the pharma industry joined the network.

4. Future-Ready Infrastructure

- Positioned to handle **serialization and full traceability** requirements for 2024 DSCSA deadline.
- Building blocks for global scalability and multi-country adoption.

Challenges Encountered

1. Industry-Wide Adoption

- Getting traditional pharma companies to adopt **new blockchain technology** required extensive education and consensus-building.

2. Integration with Legacy Systems

- Pharma supply chains still rely on **ERP and legacy tracking systems**.
- MediLedger had to build **interoperable APIs** and offer support for onboarding.

3. Data Governance and Privacy

- Ensuring **confidentiality** in a decentralized network posed a major technical challenge.
- MediLedger solved this using **Zero-Knowledge Proofs and hashed pointers** to off-chain data.

Key Takeaways

Area	**Outcome**
Compliance	DSCSA-ready product verification and ATP registry
Efficiency	Reduced verification times from days to seconds
Security	Tamper-proof audit trail for product transactions
Trust	Built a trusted network without central data ownership
Innovation	Demonstrated real-world blockchain utility in pharma

Conclusion

The **MediLedger Project** is one of the most advanced real-world implementations of blockchain in healthcare. By uniting competitors on a **neutral, decentralized platform**, it not only ensures compliance with DSCSA mandates but also sets a precedent for **transparent, efficient, and secure** pharmaceutical supply chains. As the 2024 DSCSA deadline nears, MediLedger is poised to be a **central player** in the future of pharmaceutical logistics.

RESEARCH METHODOLOGY

Research methodology is a way to systematically solve the research problem. It may be understood as a science of studying howresearch is done scientifically. In it we study the various steps that are generally adopted by a researcher in studying his research problem along with the logic behind them. It is necessary for the researcher to know not only the research methods or techniques but also the methodology.

Data Collection Source

Information was collected through both primary and secondary sources.

- **Primary Data:** In some cases the researchers may realize the need for collecting the first hand information. As in the everyday life, if we want to have first hand information or any happening or event, we either ask someone who knows about it or we observe it ourselves, we do the both. Thus, the two method by which primary data can be collected is observation and questionnaire.
- **Secondary Data:** Any data, which have been gathered earlier for some other purpose, are secondary data in the hands of researcher.

Those data collected first hand, either by the researcher or by someone else, especially for the purpose of the study is known as primary data.

The data collected for this project has been taken from the secondary source.

Sources of secondary data are :-

Internet

- Magazines
- Publications
- Newspapers
- Brouchers

LIMITATIONS

- The data is collected from secondary source due to lack of time for preparing the project.

RESULTS

Here I take data of Wipro company which use Blockchain technology in their Supply chain management.

Wipro: Blockchain Technology in Supply Chain Management

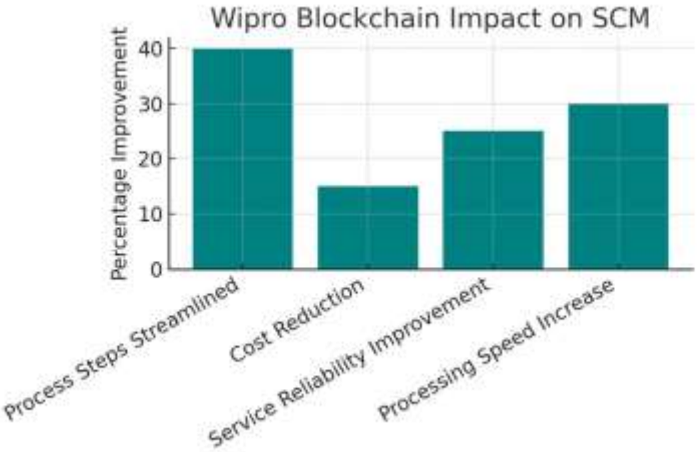
Company Overview: Wipro Ltd. is a global leader in information technology, consulting, and business process services. The company has adopted blockchain technology to transform supply chain operations across industries.

Blockchain in Supply Chain: Wipro uses blockchain for real-time shipment tracking, anti-counterfeit verification, automated procurement, and smart contracts to optimize supply chain performance.

Quantitative Achievements

Metric	Value (in % or $M)
Process Steps Streamlined	40
Cost Reduction	15
Service Reliability Improvement	25
Processing Speed Increase	30
Investment in SCM Tech	300

Graphical Representation



1. Process Efficiency Enhancement

Achievement: Streamlined up to 40% of process steps in selected functions.

Implementation: By integrating blockchain into supply chain operations, Wipro enabled real-time shipment status updates, reduced extensive communication mechanisms, and eliminated multiple systems, leading to significant annual savings for enterprises.

2.Cost Reduction

Achievement: Achieved a cost reduction of approximately 10–15% across various segments.

Implementation: Wipro's efficient supply chain network, enhanced by blockchain technology, ensured timely production and delivery, significantly reducing operational costs.

Editable Templates

3. Service Reliability Improvement

Achievement: Improved service reliability by around 25%.

Implementation: Client feedback indicated enhanced customer satisfaction due to Wipro's blockchain-enabled supply chain initiatives.

4. Processing Speed Increase

Achievement: Increased processing speed by 30%.

Implementation: Investment in supply chain management technologies, including blockchain, led to faster processing times.

5. Investment in Supply Chain Technologies

Achievement: Invested $300 million in the last fiscal year.

Implementation: Focused on automation and AI integration within supply chain management, bolstered by blockchain solutions.

Editable Templates

6. Implementation of Blockchain Platform for Energy Sector

Achievement: Developed and implemented a blockchain-based small-scale liquefied natural gas (ssLNG) trading platform.

Implementation: In collaboration with Uniper, Wipro's platform simplified the commodity supply chain, enabling growth in the logistics-heavy decentralized LNG-for-trucks business.

7. Development of Blockchain Solutions Across Sectors

Achievement: Developed nine blockchain-based solutions for various industries.

Implementation: Wipro's Blockchain Innovation Lab created solutions spanning banking, financial services, insurance, manufacturing, retail, and consumer goods, addressing areas like anti-counterfeit solutions and supply chain traceability.

- In order to examine the trend of research, a search on publications related to blockchain was carried out, and the number of publications is shown in fig.1,. The evidence shows that in the year 2023, 62 publications on blockchain technology were made, reflecting a high number in comparison with the preceding years. As can be seen in fig.2, , the computer science field has contributed most to the research on blockchain technology. Further, as shown in fig.3, , research articles make up a larger proportion of blockchain publications compared to other categories, such as news articles, review articles, and book chapters.

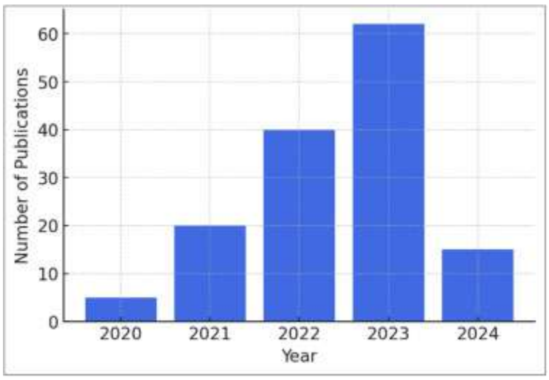


Fig. 1. Year wise publication.

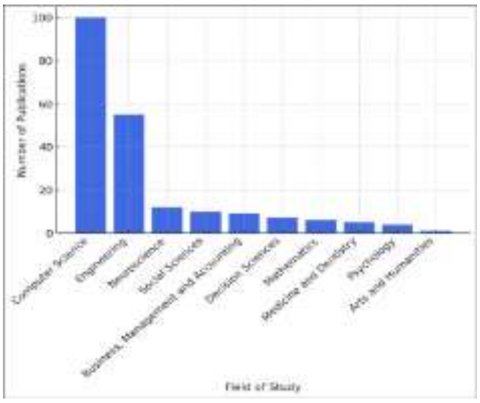


Fig. 4. Number of publications and subject area.

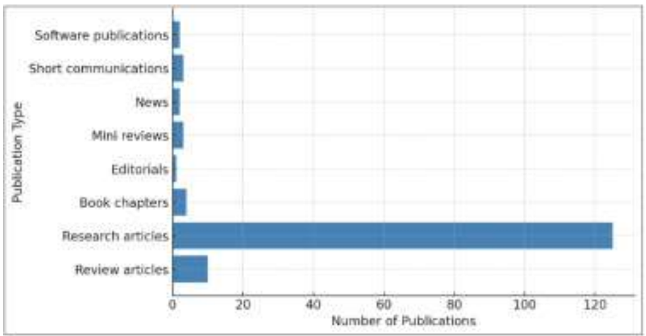


Fig. 5. Number of publications, including various article categories.

This paper describes blockchain use cases across various sectors, its strengths, weaknesses, and future improvements. The key contribution of this paper includes:

- **(i)Industry Analysis:** Explains blockchain usage in supply chain, healthcare, finance, real estate, and IoT.

- **(ii)Blockchain Typology:** Describes blockchain as public, private, hybrid, and consortium types.

- **(iii)Innovations:** Talks about smart contracts, identity management, and AI-integrated blockchain solutions.

- **(iv)Challenges & Solutions:** Addresses scalability, interoperability, regulations, and energy costs and proposes effective algorithms and policies.

- **(v)Future Directions:** Emphasizes pointing out 6 G security, decentralized AI, and sustainable blockchain integration.

Application of blockchain techniques in industries

Different sectors have adopted blockchain technology with innovations in both design and applications. It facilitates cross-border payments in finance and banking, helps with the execution of smart contracts in a manner that increases the levels of efficiency and reduces time, supports secure management of electronic health records in healthcare, and enhances the integrity of clinical trials. In real estate, it finds use in property title management and in tokenizing real estate for fractional ownership, enabling easier transactions.

Fig:4, shows the exponential growth in the application of blockchain technology. In the healthcare sector, blockchain improves clinical trials by enhancing reproducibility and transparency through the recording of trial data and verification of results. This ensures transparency and accuracy are maintained in research processes. In intellectual property, blockchain provides a secure mechanism for digital rights management. It ensures fair compensation for creators and protects their intellectual property, hence fostering trust and fairness. The gaming and entertainment industry benefits from blockchain through the use of smart contracts, which guarantee royalty payments and enable fair income sharing. Blockchain also allows players to own and exchange digital assets outside gaming systems, enhancing ownership and flexibility. In the case of voting and governance, blockchain ensures decentralized governance, which opens the decision-making process and ensures more transparency. Additionally, blockchain allows for secure voting with traceability, reducing fraud within a supply chain, as mentioned by.

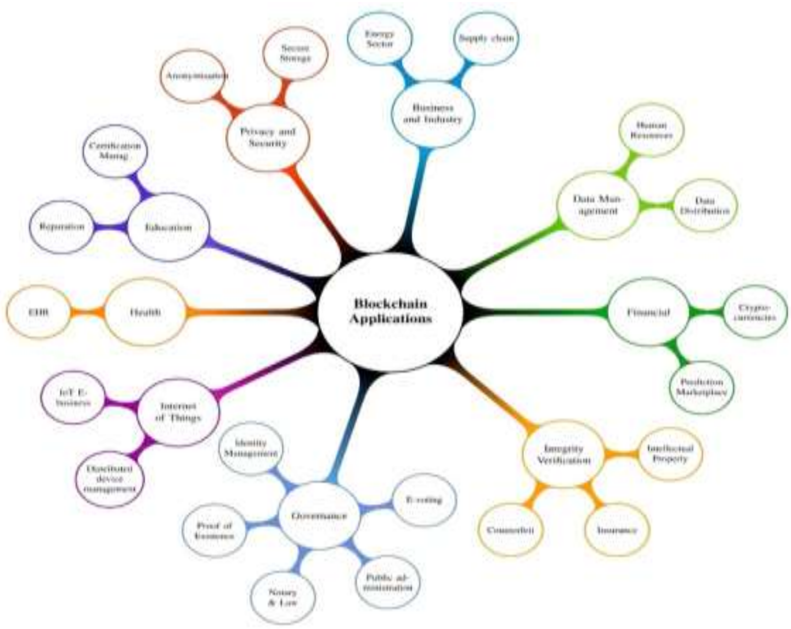


Fig: 4, Applications of Blockchain

In government and public services, blockchain secures the issuance of digital identities and cuts bureaucracy. The decentralized nature of the technology promotes trust in administrative procedures. In a similar way, supply chain management benefits from blockchain because it can maintain traceability and transparency, thereby reducing fraud and ensuring the authenticity of merchandise. These applications underpin the transformative potential of blockchain across many domains.

Blockchain techniques in supply chain management

Supply chain management incorporates various blockchain techniques that can enhance traceability, security, and efficiency. It also allows supply chain finance to provide smooth processes of payment and builds trust in transactions between different parties. This blockchain technology makes it easier for compliance and auditing by recording regulatory data in a secure manner and prevents counterfeiting because the verification of goods' authenticity is obtained. Blockchain further enhances supplier management through the tracking of supplier reputations and allows collaboration by sharing data and enabling interoperability. It also contributes to sustainability and ethical sourcing since it guarantees transparency in material sourcing. By addressing key points, blockchain drives greater efficiency, accountability, and transparency across supply chains. Fig. 7 illustrates some of these blockchain techniques, while Table 2 describes specific applications of these techniques in supply chain management.

Fig. 7. Blockchain techniques in supply chain management.

Reference	Industry/service provider	Address the problems	Concept	Solution	Benefits
	Transportation	There is a requirement for more information about the provenance of the goods, lack of updated information, and hence, the difficulty of tracking the movement of the goods	Details of the duration of delivery, confirmation of receipt of the product, and status of shipment that was safely stored in a block then went into the blockchain..	Under a blockchain based supply chain, the data is verified and thereafter kept within the blockchain network. The immutability of the blockchain guarantees that the data stays unchangeable and unopposed to falsifying. As so, the recipient of	The enhanced credibility and transparency of the supplier chain.

Reference	Industry/service provider	Address the problems	Concept	Solution	Benefits
				such material might be quite confident in its accuracy and validity. Once the provider has kept data inside the blockchain network, it becomes accessible.	
	Industry 3.0 and Industry 4.0 in manufacturing	Capturing and storing substantial data with blockchain technology is a significant endeavour.	Integrated blockchain technology with distributed storage mechanisms to present a blockchain-based solution tailored for the supply chain domain.	The Inter Planetary File System (IPFS) provides an actual, real-world solution. IPFS is distributed file system that tries to connect all computational devices with a unified file system. IPFS allows people to use vast amounts of data and then add the immutable and permanent IPFS links into a transaction in a blockchain.	Blockchain technology together with distributed storage enhances supply chain system appropriate for next-generation industry.
	Food and Beverages, Automotive Sector, Aerospace sector, Textile and Apparel, Shipping and logistics	Traceability	Distributed ledger technology (DLT) based supply chain tracking solutions	Based on the underlying reasons and intended goals of applying traceability measures, a new method founded on empirical data to define the degree of Supply Chain Traceability (SCT).	Enhances transparency, ensures compliance, improves efficiency.
	Cobalt industry	The monitoring of the performance of environmental,	A framework is required to establish a connection	Constructed blockchain designs that are both interoperable and	Enhances ESG monitoring by ensuring compliance,

Reference	Industry/service provider	Address the problems	Concept	Solution	Benefits
		social, and governance (ESG) and compliance within sectors characterized by inadequate regulatory and institutional frameworks.	between blockchain source data and Environmental, Social, and Governance (ESG) measures.	comprehensible.	transparency, and interoperability in sectors with weak regulatory frameworks.
	Agri-based industry	Issues with factory monitoring	The Ethereum blockchain technology is used to monitor and record the activity of shareholders.	IoT play a crucial role in generating and using digital data across the distribution process, intending to achieve enhanced transparency and traceability.	Enhance transparency and traceability in the Agri-based industry
	COVID-19 vaccines	Detection of COVID-19 vaccines and supply chain traceability.	A network based on blockchain technology.	Integration of private and public blockchains helps to boost transaction capacity. Helping to standardize and govern the data flow could depend on blockchain technologies.	Immutable Vacledger is linked to distributed peer-to-peer file systems that record everything that has ever happened and every transaction that has ever been made.
	Agri-food	Traceability	Smart contracts are used in a multi-agent system to streamline supply chain management. To record all transactions of supply chain, use the blockchain	Blockchain-based supply chain model with integrated agent automation.	Enhances COVID-19 vaccine detection and supply chain traceability

Reference	Industry/service provider	Address the problems	Concept	Solution	Benefits
			technology.		
	Bunker supply	Successful Resolution of Bunker Quality Concerns	Blockchains can be additionally used to validate electronic bunker delivery notes to improve quality and quantity bunker disputes and the new International Maritime Organization 2020 regulations.	Bunker	

Blockchain technology is extensively used in supply chain management to enhance efficiency, traceability, and trust. Distributed ledger technology ensures that events occurring within the supply chain are securely recorded in a tamper-resistant manner. Every participant retains a copy of the transaction record, minimizing data modification risks. Smart contracts automate various supply chain processes, including fulfilment, payment settlement, and compliance inspections. These contracts guarantee the instant execution of predefined actions, which can be releasing payments right after shipment delivery.

Blockchain helps to enhance traceability and provenance by recording a product's journey right from raw materials to the end user. This ensures authenticity and thus easy identification of problems or rejections in a very short time. The integration of RFID and IoT with blockchain, as explained by, improves visibility through the secure recording of data obtained from tracking devices, which enables the real-time monitoring of goods. Blockchain-based solutions revolutionize supply chain finance by improving transaction visibility and reducing risks related to financing and inventory levels. The solutions make it easier for suppliers to obtain credit and

Blockchain in the industries

There has been great attention to blockchain technology across various sectors, with a wide adoption. The distributed database system basically makes the record of data and transactions in a decentralized computer network, securely and transparently. It's a new innovation to an old problem in industries. While all these eventualities are expected of it, the system faces many challenges in terms of regulatory uncertainty and scalability. However, with the help of continuous research and development, such obstacles are likely to be abated. As the technology develops further, we can expect more innovative and practical uses of blockchain throughout various industries. Table:2, provides an overview of blockchain technologies being used in many industries.

Table 2. Blockchain scope for industries.

	Coffee Industry	A framework for changing the supply chain business processes of coffee industry with uses of blockchain-capable workflows.
	Railcar industry	Life cycle assessment (LCA) methodology is employed to facilitate tracking components and orders throughout the supply chain (SC) of railcar remanufacturing. The research focused on enhancing Product Lifecycle Management (PLM) by integrating blockchain and Configuration Management (CM) for traceability, using Supply Chain (SC) information systems.
	Textile and clothing industry	Using the mass balancing validation procedure, the operational illustration of a blockchain framework is used to establish traceability for organic cotton.
	Oil industry	Blockchain technology is strongly advised for intricate and interconnected supply chain networks, particularly within the oil sector. The relationship between Blockchain technology attributes and supply chain management methods may help managers and decision-makers understand how to use Blockchain in actual scenarios.
	Textile and clothing	Distributed ledger technology (blockchain) architecture for Internet of Things (IoT) applications facilitate commercial transactions between various entities in the garment industry's supply chain. A blockchain-based distributed ledger and Internet of Things applications collaborating to provide transaction services within a global textile consortium. The IoT is a global network for the sentient in which interconnected objects that communicate with one another through standardized protocols and individual addressing schemes to achieve shared objectives in collaboration with other network nodes and external business partners. Decisions in the apparel industry could be facilitated by the data collected by Internet of Things applications throughout the supply chain.
	Fashion Industry	Researchers proposed that blockchain may provide transparency and trust in the supply chain., therefore protecting consumers and stakeholders against greenwashing. This technology exposes greenwashing, which might backfire for businesses not doing the right thing. Additionally, corporations cannot conceal unsustainable behaviours using blockchain.
	Food	Demonstrate a blockchain-based quality control framework tailored for localized food delivery networks.
	Food	Implementing a blockchain based service system for pharmaceutical with aims to address many issues, including limited efficacy, lack of transparency, and susceptibility to data tampering. The solution encompasses the whole recall process, which contains decision-making, the examination of out-of-specification/out-of-trend (OOS/OOT) occurrences, the actions taken by the working group, the implementation of Corrective and Preventive Actions (CAPA) a recall management system enables the reduction of time, improvement of

		transparency, and safeguarding of data integrity in the context of pharmaceutical recalls.
	Supply chain finance	Proposed a new approach using IoT and Blockchain technologies to handle data in Supply Chain Finance (SCF), called BC4Regu, the suggested structure solves information asymmetry. BC4Regu is used in several contexts, and its usefulness is validated by a theoretical study applying the principle-agent model.

Blockchain implementation in the renewable energy sector is still underdeveloped compared to its implementation for supply chain, textile, and pharmaceutical use cases. There appears to be a lack of end-to-end studies of the use of blockchain and AI/ML for predictive analysis in the energy market as well as fault detection. P2P energy trading through blockchain technology is still in its infancy without defined regulations for real-time-based transactions as well as settlements with smart contracts. In addition, regulatory and policy impediments remain obstacles to blockchain implementation in energy markets and need further exploration.

Data privacy and security concerns arise despite blockchain's immutability and inherent security features, especially in sectors handling sensitive information. It would also be important to minimize these challenges with the help of permissioned blockchains that have restricted access, methods of encryption, and sophisticated techniques such as homomorphic encryption and zero-knowledge proofs for privacy in public blockchains. Energy consumption remains another issue, especially about Proof-of-Work mechanisms, which are seen as very harmful to the environment. Moving toward energy-efficient models like Proof-of-Stake or the utilization of renewable energy sources already decreases these issues, while hybrid or private blockchains further enhance the efficiency of this technology . The high costs associated with blockchain implementation and the need for clear return on investment (ROI) metrics poses additional challenges. Conducting cost-benefit analyses and emphasizing high-impact use cases can demonstrate value and encourage investment .

DISCUSSION AND ANALYSIS

There are regulatory uncertainties and a lack of standardized policies on the widespread adoption of blockchain. The challenges of real-world implementation include the fact that a shift from traditional supply chains to blockchain-based systems is very challenging for any organization. Several challenges are related to training, change management, and technical hurdles. All these require sufficient consideration and planning from business. Another issue that needed more research involved the environmental impact due to blockchain technology. The consensus mechanisms of blockchain networks, especially the proof-of-work-type consensus mechanism, have faced criticism for the high amounts of energy they use.

Other than these technological challenges, scholars have also queried the factors determining the uptake and resistance to adopting blockchain in supply chains. Resistance to change, transparency, and trust were critical factors in deciding whether supply chain stakeholders would take up blockchain technology. It is extremely crucial to know these variables in an effort to enhance broad acceptance and universal adoption. Another significant facet under discussion is the maturity of smart contracts. Smart contracts, despite their huge potential in automating supply chain processes, are still constrained in addressing complicated business logics and real-world scenarios. Researchers have put efforts into enhancing and adjusting smart contracts for improved supply chain management needs. The potential of blockchain to further sustainable supply chains has also drawn a lot of interest. The technology makes it possible to trace and authenticate environmental and ethical credentials to guarantee supply chains align with sustainability goals. Researchers have researched how blockchain can enhance transparency and accountability in sustainability-focused supply chains . Regulatory uncertainties remain a nagging problem. To mitigate against this, there have been calls by some scholars for regulatory sandboxes risk-free places in which blockchain projects may be tested against rising regulatory standards and thereby bridge the gap between innovation and compliance.

The increased influence of blockchain is being seen in terms of higher number of adoptions and pilots. Future trends imply more interconnectedness between sectors with higher interoperability and improved multi-tiered supply chain visibility. Technologies such as digital identity authentication, supply chain financing, and IoT integration will likely make improvements. Moreover, decentralized marketplaces, efforts at sustainability, and ESG tracking will also be among the driving forces in shaping the future of blockchain in supply chains. While the energy needs of blockchain are still a subject of concern, energy-efficient consensus algorithms are already being studied. Hybrid designs combining elements of both public and private blockchain networks are also under development to optimize efficiency and scalability.

Smart contracts can be daunted in complex value chains by costly integration and trust problems. A lack of technical expertise and the complexity of integrating blockchain deter adoption, especially in healthcare organizations. Prohibitive costs, uncertainty of ROI, governance, and industry competition also slow down adoption. Organizational resistance to change and legal challenges, such as liability in decentralized networks, also pose challenges. Ethical concerns of data ownership and consent must be addressed. Improving user experience and enabling collaboration among stakeholders will be key to more pervasive blockchain adoption as the technology evolves.

CONCLUSION

Blockchain technology has demonstrated significant potential to transform supply chain management by addressing longstanding challenges such as lack of transparency, inefficiency, and limited traceability. Through its decentralized, immutable, and secure structure, blockchain enables seamless and trustworthy data sharing among supply chain participants, enhancing operational integrity and stakeholder confidence.

The case studies of IBM Food Trust with Walmart and the MediLedger Project in the pharmaceutical sector illustrate how blockchain adoption leads to real-time traceability, faster verification, fraud prevention, and regulatory compliance. These practical implementations underscore the technology's ability to streamline operations, reduce risks, and elevate consumer trust.

Survey findings from this study also confirm that organizations recognize the strategic value of blockchain, particularly in enhancing traceability, security, and automation. However, adoption remains limited due to high implementation costs, lack of technical expertise, integration difficulties, and regulatory uncertainty. These challenges must be addressed through collaborative efforts, supportive policies, and industry-wide standards to unlock the full benefits of blockchain.

Furthermore, as blockchain continues to evolve—integrating with technologies such as IoT, AI, and smart contracts—it will play an increasingly central role in building transparent, ethical, and sustainable supply chains. Businesses that embrace this transformation early will be better positioned to drive innovation, meet compliance standards, and gain competitive advantage in the global marketplace.

In conclusion, while blockchain is not a universal solution, it represents a critical enabler for modernizing and future-proofing supply chain ecosystems. Continued research, policy development, and stakeholder engagement are essential for fostering widespread adoption and maximizing its long-term impact.

\Discussion and Limitation

Table 2. Evolutionary transformation of Blockchain technology.
BCT 1.0
Bitcoin—"The Mother of All
Blockchain."
BCT 2.0

Ethereum
BCT 3.0
Hyperledger
BCT 4.0
Industry

CONCLUSIO

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APPENDICES

Annexure 1: Survey Questionnaire

Section 1: Respondent Profile

1. **What is your current role in your organization?**
   - ☐ Supply Chain Manager
   - ☐ IT/Technology Manager
   - ☐ Procurement Officer
   - ☐ Logistics Coordinator
   - ☐ Executive/Decision-Maker
   - ☐ Other (please specify): ____________
2. **Which industry does your organization operate in?**
   - ☐ Manufacturing
   - ☐ Retail
   - ☐ Healthcare
   - ☐ Agriculture
   - ☐ Logistics/Transportation
   - ☐ Other (please specify): ____________
3. **How large is your organization?**
   - ☐ Fewer than 50 employees
   - ☐ 50–199 employees
   - ☐ 200–999 employees

- ☐ 1,000+ employees

Section 2: Awareness and Understanding

4. **How familiar are you with blockchain technology?** *(Likert scale)*
   - ☐ Not at all familiar
   - ☐ Slightly familiar
   - ☐ Moderately familiar
   - ☐ Very familiar
   - ☐ Expert

5. **How would you rate your understanding of blockchain applications in supply chain management?** *(Likert scale)*
   - ☐ Very poor
   - ☐ Poor
   - ☐ Average
   - ☐ Good
   - ☐ Excellent

Section 3: Adoption and Implementation

6. **Has your organization adopted blockchain technology in its supply chain operations?**
   - ☐ Yes
   - ☐ No
   - ☐ Planning to adopt
   - ☐ Not sure

7. *(If yes)* **For which supply chain functions is blockchain being used?** *(Select all that apply)*
   - ☐ Procurement and sourcing
   - ☐ Inventory management
   - ☐ Logistics and transportation

- ☐ Quality control and compliance
- ☐ Traceability and transparency
- ☐ Payments and smart contracts
- ☐ Other: ___________

8. *(If no)* **What are the main reasons your organization has not adopted blockchain technology?** *(Select all that apply)*

- ☐ Lack of awareness
- ☐ High implementation cost
- ☐ Lack of technical expertise
- ☐ Integration challenges
- ☐ No clear business need
- ☐ Regulatory uncertainty
- ☐ Other: ___________

Section 4: Perceived Benefits and Challenges

9. **What benefits do you associate with blockchain in supply chain management?** *(Select all that apply)*

- ☐ Increased transparency
- ☐ Improved traceability
- ☐ Enhanced security
- ☐ Reduced fraud
- ☐ Better efficiency and automation
- ☐ Cost savings
- ☐ Other: ___________

10. **What challenges do you foresee or have experienced in implementing blockchain?** *(Select all that apply)*

- ☐ Lack of skilled personnel
- ☐ High setup and maintenance costs

- ☐ Data privacy concerns
- ☐ Resistance to change
- ☐ Scalability issues
- ☐ Interoperability with existing systems
- ☐ Other: ___________

Section 5: Future Outlook and Recommendations

11. **How likely is your organization to invest in blockchain technology within the next 1–3 years?**

- ☐ Very unlikely
- ☐ Unlikely
- ☐ Neutral
- ☐ Likely
- ☐ Very likely

Annexure 2: Summary of Survey Responses

Section 1: Respondent Profile

Current Role in the Organization

- Supply Chain Manager – 28%
- IT/Technology Manager – 22%
- Procurement Officer – 15%
- Logistics Coordinator – 10%
- Executive/Decision-Maker – 18%
- Other – 7% (e.g., Consultants, Analysts)

Industry of Operation

- Manufacturing – 30%
- Retail – 20%
- Healthcare – 10%
- Agriculture – 8%
- Logistics/Transportation – 25%

- Other – 7% (e.g., Energy, Automotive)

Organization Size

- Fewer than 50 employees – 15%
- 50–199 employees – 25%
- 200–999 employees – 35%
- 1,000+ employees – 25%

Section 2: Awareness and Understanding

Familiarity with Blockchain Technology

- Not at all familiar – 5%
- Slightly familiar – 18%
- Moderately familiar – 40%
- Very familiar – 25%
- Expert – 12%

Understanding of Blockchain in Supply Chain

- Very poor – 3%
- Poor – 10%
- Average – 45%
- Good – 32%
- Excellent – 10%

Section 3: Adoption and Implementation

Has Your Organization Adopted Blockchain?

- Yes – 30%
- No – 45%
- Planning to adopt – 20%
- Not sure – 5%

(If Yes) Blockchain Use Cases *(multiple selections allowed)*

- Procurement and sourcing – 45%
- Inventory management – 55%
- Logistics and transportation – 60%
- Quality control and compliance – 30%

- Traceability and transparency – 70%
- Payments and smart contracts – 40%
- Other – 5% (e.g., Customs, Certification)

(If No) Barriers to Adoption *(multiple selections allowed)*

- Lack of awareness – 35%
- High implementation cost – 55%
- Lack of technical expertise – 48%
- Integration challenges – 30%
- No clear business need – 25%
- Regulatory uncertainty – 20%
- Other – 10% (e.g., Internal resistance)

Section 4: Perceived Benefits and Challenges

Perceived Benefits *(multiple selections allowed)*

- Increased transparency – 78%
- Improved traceability – 70%
- Enhanced security – 60%
- Reduced fraud – 50%
- Better efficiency and automation – 65%
- Cost savings – 40%
- Other – 5%

Challenges Faced or Expected *(multiple selections allowed)*

- Lack of skilled personnel – 50%
- High setup and maintenance costs – 58%
- Data privacy concerns – 35%
- Resistance to change – 42%
- Scalability issues – 28%
- Interoperability with existing systems – 45%
- Other – 7% (e.g., Lack of leadership support)

Section 5: Future Outlook

Likelihood of Blockchain Investment in Next 1–3 Years

- Very unlikely – 5%
- Unlikely – 15%
- Neutral – 30%
- Likely – 35%
- Very likely – 15%