BLOCKCHAIN SOLUTION FOR MEDICAL SUPPLY IMBALANCE

BACHELOR OF TECHNOLOGY

IN

COMPUTER SCIENCE AND ENGINEERING

Use Case Report

submitted by

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Kanuru, Vijayawada-520 007

2024-25

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CERTIFICATE

This is to certify that the Use Case report entitled **"Blockchain Solution for Medical Supply Imbalance"** that is being submitted by **Katta Jaya Siva Srithan (22501A0580)**, as part of Assignment-1 and Assignment-2 for the **Blockchain Technology(20CS4601C)** course in **3-2** during the academic year **2024-25**.

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1. INTRODUCTION

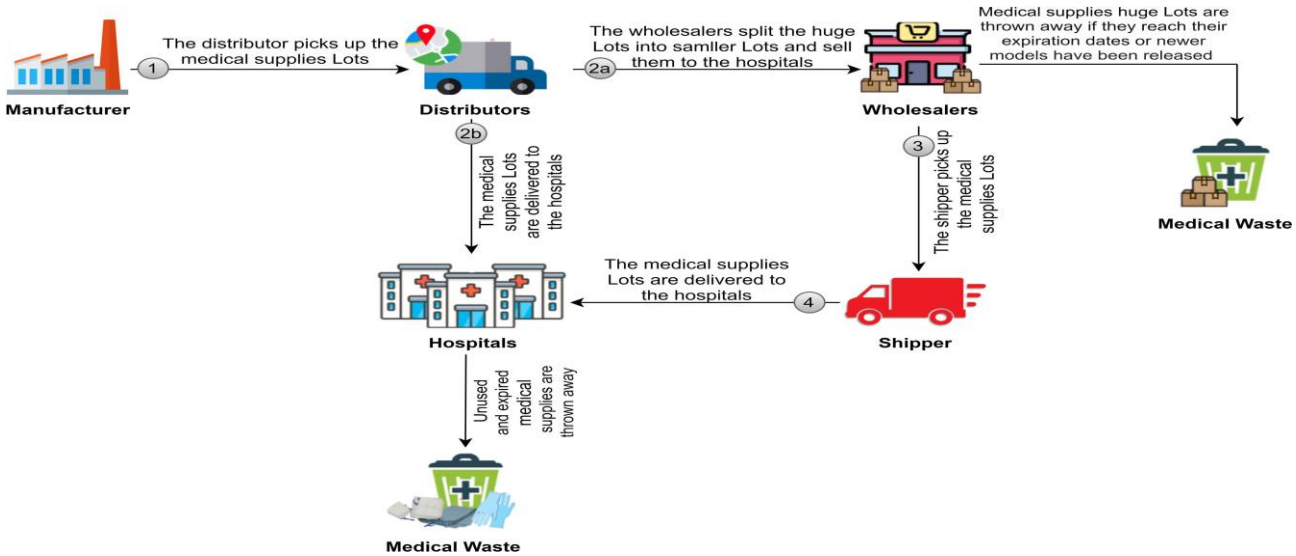
The increasing volume of medical waste has raised concerns due to its environmental and economic impacts. Studies show that hospitals dispose of vast amounts of unused medical supplies, contributing to significant financial losses and increased pollution levels [6]. The World Health Organization (WHO) categorizes healthcare waste as hazardous and emphasizes the importance of sustainable disposal mechanisms [3].

During the COVID-19 pandemic, inefficiencies in medical supply chains became evident, as certain regions suffered shortages while others experienced overproduction of essential items like personal protective equipment (PPE) [9]. According to [5], blockchain technology can mitigate such imbalances by enabling transparent, traceable, and decentralized supply chain management. The present supply chain is depicted in **Figure 1.1.**

Blockchain offers several advantages, including **real-time tracking**, **automated compliance enforcement**, and **fraud prevention**. By leveraging distributed ledger technology, stakeholders can ensure that medical supplies are allocated efficiently based on real-time demand data rather than relying on outdated procurement models [7].

Additionally, blockchain prevents counterfeit medical products from infiltrating the supply chain. As noted in [8], counterfeit drugs and fraudulent medical supplies remain a major concern in global healthcare, costing billions annually and endangering lives. Blockchain's immutable records and smart contract mechanisms offer a promising solution to verify authenticity and ensure secure transactions.

Figure 1.1 Flow diagram of production, consumption, waste generation of medical supplies



2. BACKGROUND

Traditional medical supply chains face significant **inefficiencies due to centralized control, delayed data updates, and a lack of interoperability between stakeholders**. According to [7], healthcare institutions often struggle with **supply-demand mismatches**, where critical items such as surgical tools and personal protective equipment (PPE) are either overproduced or insufficiently stocked.

One of the key challenges in traditional medical supply chains is **the lack of real-time visibility**. As stated in [10], **current inventory management systems rely on periodic manual audits**, which can lead to inaccurate stock levels and misallocation of essential supplies. This inefficiency became particularly evident during the COVID-19 pandemic, where some regions faced severe shortages while others had surplus supplies that went to waste [9].

Furthermore, **traditional supply chains heavily depend on third-party intermediaries**, increasing operational costs and creating multiple points of failure. Studies in [11] indicate that **middlemen in the medical supply chain often introduce delays in procurement, increase risks of counterfeit products, and reduce overall efficiency**. Blockchain technology, through **decentralized ledger systems and smart contracts**, can minimize reliance on intermediaries while ensuring supply authenticity and traceability [12].

Another major issue is **fraud and counterfeiting in medical logistics**. Reports show that **fake or substandard drugs enter supply chains due to weak tracking mechanisms** [13]. Blockchain, by **leveraging immutable transaction records and cryptographic verification**, provides a secure and tamper-proof system to track the origin and movement of medical supplies, ensuring authenticity and compliance [14].

Additionally, **waste management remains a pressing concern** in the healthcare sector. Improper disposal of expired medical products contributes to environmental pollution and public health risks. Research in [15] highlights that **blockchain-enabled tracking systems can monitor product lifecycles, preventing unnecessary waste and ensuring responsible disposal practices**.

3. BLOCKCHAIN BASICS

Blockchain technology operates as a **distributed, decentralized ledger** that records transactions securely and transparently. Unlike traditional centralized databases, blockchain ensures **immutability**, meaning that once a transaction is recorded, it cannot be altered or deleted [9]. This feature is particularly valuable in medical supply chains, where **tamper-proof record-keeping** ensures transparency and prevents fraudulent activities [10].

One of the most critical aspects of blockchain is **decentralization**. Traditional supply chain management systems rely on **centralized authorities**, creating single points of failure that can lead to data loss, manipulation, or inefficiencies. By contrast, blockchain enables a **peer-to-peer (P2P) network**, distributing control among multiple nodes, thereby enhancing security and data integrity [11].

Another fundamental feature of blockchain is **smart contracts**. These **self-executing contracts** contain predefined rules and automatically execute transactions when conditions are met. In a medical supply chain context, smart contracts can **automate procurement, verify supplier credentials, and track the movement of goods in real time**, eliminating the need for third-party verification [12].

Blockchain also employs **various consensus mechanisms** to validate transactions. Common mechanisms include:

- **Proof of Work (PoW):** Used in Bitcoin, but computationally expensive and energy-intensive [13].
- **Proof of Stake (PoS):** More energy-efficient, as validators are chosen based on the number of tokens held [14].
- **Proof of Authority (PoA):** Faster than PoW and PoS, where trusted validators confirm transactions, making it suitable for **private and permissioned blockchains** used in medical logistics [15].

Through **decentralization, immutability, smart contracts, consensus mechanisms, and real-time tracking**, blockchain **enhances the efficiency, security, and transparency** of medical supply chains [17].

4. USE CASE OVERVIEW

Blockchain technology in the medical supply chain involves multiple stakeholders, each with distinct roles in ensuring efficiency, security, and transparency. According to [9], traditional supply chains often suffer from inefficiencies due to fragmented record-keeping and reliance on intermediaries, leading to supply mismatches and increased costs. By leveraging blockchain, stakeholders can directly interact with verified data, ensuring **real-time tracking, smart contract automation, and decentralized verification** [17].

Key Stakeholders in a Blockchain-Based Medical Supply Chain

- **Manufacturers**: Responsible for recording product details, such as batch numbers, expiration dates, and quality verification. Research in [12] highlights how **blockchain prevents counterfeiting** by ensuring that only authenticated products enter the supply chain.
- **Distributors**: Transport and store medical supplies, ensuring compliance with regulatory standards. As stated in [10], real-time tracking using blockchain reduces theft and supply chain fraud by **providing immutable proof of shipment history**.
- **Healthcare Providers (Hospitals & Clinics)**: Use blockchain to verify product authenticity, manage inventory efficiently, and reduce waste. According to [14], **automated inventory updates help prevent overstocking and reduce medical waste**, which has been a persistent issue in traditional supply chains.
- **Regulatory Bodies**: Monitor compliance with safety regulations and ensure ethical procurement practices. A study in [16] emphasizes that **blockchain enhances regulatory oversight** by allowing authorities to track product origins, storage conditions, and distribution records in real time.

System Workflow

1. **Registration and Authentication**: Stakeholders register on the blockchain, ensuring **identity verification and secure access to supply chain data** [18].
2. **Production Recording**: Manufacturers log production data, ensuring transparency and enabling **end-to-end traceability of medical supplies** [11].

3. **Smart Contract Execution**: Smart contracts enforce agreements between manufacturers, distributors, and healthcare providers, **automating payments and compliance checks** [19].
4. **Real-Time Tracking**: As stated in [20], blockchain **provides live tracking of shipments**, ensuring products are stored and delivered under optimal conditions.
5. **Inventory Management**: Hospitals and clinics use blockchain to monitor stock levels and anticipate demand, **reducing supply shortages and preventing expired stock buildup** [13].
6. **Regulatory Oversight**: Authorities access blockchain records to **audit supply chain activities, detect fraud, and enforce safety standards** [15].

By integrating blockchain, the **medical supply chain becomes more transparent, efficient, and resilient**, addressing key challenges faced by traditional systems [22].

5. IMPLEMENTATION

The implementation of blockchain in medical supply chains requires **a well-structured approach to integrating decentralized ledger technology with existing systems**. As noted in [9], transitioning from traditional supply chain management to blockchain-based solutions **involves technical, regulatory, and logistical considerations**. The implementation process can be categorized into **blockchain network selection, smart contract deployment, integration with tracking systems, and security measures**.

5.1 Blockchain Network Selection

Choosing the appropriate blockchain framework is critical for performance and security. The solutions proposed in [19]–[21], and our solution used the Ethereum network, while [17] used the Hyperledger Besu [21] that was implemented in a public mode. According to [12], **Ethereum-based smart contracts provide flexibility for automated medical supply agreements**, while permissioned blockchains like Hyperledger Fabric offer **greater control and compliance with industry regulations**.

5.2 Smart Contract Deployment (Using Remix IDE)

Smart contracts play a pivotal role in **automating and enforcing agreements** between supply chain stakeholders. As described in [14], **self-executing contracts eliminate the need for intermediaries by ensuring compliance with predefined terms**, such as **automatic payment releases upon verified delivery**.

For Ethereum-based implementation, **Remix IDE was used to develop, test, and deploy smart contracts** efficiently. Remix IDE provides **a web-based development environment**, allowing developers to **write Solidity contracts, debug transactions, and interact with the blockchain seamlessly** [16]. The integrated compiler and testing tools **streamline the contract deployment process, ensuring smooth execution on the Ethereum network** [18].

5.3 Integration with Tracking Systems

To enable **real-time monitoring**, blockchain is integrated with **IoT devices, RFID scanners, and GPS tracking**. As noted in [10], this combination allows stakeholders to **monitor shipments in transit, verify storage conditions, and detect tampering in real time**. Studies in [18] emphasize that blockchain-powered tracking ensures that **medications and medical**

equipment remain within approved temperature and humidity ranges, preventing spoilage and waste.

5.4 Security Measures and Data Privacy

Ensuring **data integrity and cybersecurity** is a critical aspect of blockchain implementation. According to [22], blockchain systems utilize **cryptographic encryption and access control mechanisms** to protect sensitive medical supply chain data. Furthermore, **multi-signature authentication and zero-knowledge proofs** can be employed to **prevent unauthorized access and ensure compliance with regulatory policies** [23].

By implementing blockchain with **the right network selection, smart contract automation via Remix IDE, IoT integration, and security enhancements**, medical supply chains can achieve **unparalleled transparency, efficiency, and trustworthiness** [24].

6. BENEFITS

The integration of blockchain technology in medical supply chains offers **numerous advantages**, addressing critical inefficiencies and improving **transparency, efficiency, security, and waste reduction**. As highlighted in [9], traditional supply chains suffer from **manual data entry errors, supply mismatches, and counterfeit risks**, all of which blockchain can effectively mitigate.

6.1 Transparency and Traceability

Blockchain ensures **full visibility** across the supply chain by maintaining **an immutable, tamper-proof ledger** of all transactions. According to [12], this **eliminates data manipulation**, enabling manufacturers, distributors, healthcare providers, and regulators to **access real-time information on product origins, movement, and storage conditions**.

Additionally, **counterfeit detection** is significantly improved. As stated in [14], counterfeit drugs account for **a significant portion of global pharmaceutical fraud**, posing risks to public health. Blockchain's **cryptographic security mechanisms** prevent unauthorized alterations, ensuring that only **genuine, verified medical supplies** enter the market.

6.2 Efficiency and Cost Reduction

By automating supply chain processes, blockchain **eliminates administrative overhead and reduces reliance on third-party intermediaries**. Research in [16] highlights that smart contracts can **automate order validation, payment processing, and compliance verification**, reducing delays and minimizing transaction costs.

Moreover, **streamlined inventory management** enables **real-time tracking of stock levels**, ensuring **on-time replenishment** and preventing shortages or excess inventory. According to [18], blockchain-powered supply chain systems **enhance operational efficiency by up to 30%**, leading to substantial cost savings for healthcare organizations.

6.3 Security and Fraud Prevention

Blockchain's **decentralized architecture** and **cryptographic encryption** protect supply chain data from cyberattacks and unauthorized access. As stated in [20], traditional supply chains are vulnerable to **data breaches and fraudulent modifications**, whereas blockchain provides a **secure, immutable record of all transactions**.

Additionally, **multi-signature authentication mechanisms** ensure that only authorized personnel can approve supply chain transactions, reducing the risk of internal fraud [22]. The use of **zero-knowledge proofs** further enhances privacy by allowing verification of information without exposing sensitive data [23].

6.4 Waste Reduction and Sustainability

One of the major concerns in healthcare logistics is **medical waste accumulation due to overproduction and mismanagement**. Research in [10] suggests that blockchain can **optimize production cycles and improve demand forecasting**, reducing unnecessary medical waste.

Furthermore, blockchain supports **circular economy models**, enabling the redistribution of **near-expiry but still usable** medical supplies to areas in need, minimizing waste [15]. The system also aids in **tracking the environmental impact of medical supply chains**, ensuring compliance with sustainability regulations [24].

By providing **transparency, efficiency, security, and sustainability benefits**, blockchain **transforms medical supply chain management**, ensuring better resource utilization and improved patient outcomes [17].

7. CHALLENGES

Despite its numerous advantages, the implementation of blockchain in medical supply chains faces **several challenges**, including **regulatory barriers, scalability issues, adoption resistance, and high initial costs**. As highlighted in [9], while blockchain enhances supply chain transparency, its widespread adoption in the healthcare industry is hindered by **technological and operational complexities**.

7.1 Regulatory Compliance and Legal Barriers

The **strict regulatory environment** surrounding medical supply chains creates challenges in **aligning blockchain-based systems with existing compliance requirements**. As noted in [12], healthcare regulations such as **GDPR, HIPAA, and FDA guidelines** impose **data privacy and security restrictions** that must be carefully managed when integrating blockchain solutions.

Furthermore, blockchain's **immutability** poses a legal challenge in scenarios where **data modification or deletion is required for compliance** [14]. The lack of **clear global regulatory standards** for blockchain-based supply chains makes **legal adoption inconsistent across different jurisdictions** [16].

7.2 Scalability and Performance Constraints

Blockchain networks often struggle with **scalability issues**, particularly in handling **large transaction volumes and high-speed processing**. As mentioned in [18], traditional blockchain networks, such as Ethereum, experience **high transaction fees and slower processing speeds**, limiting their feasibility for real-time medical supply chain operations.

To address this, **layer-2 scaling solutions** and **private blockchain implementations** have been explored, but these require additional technical infrastructure and investment [20].

7.3 Adoption Resistance and Integration Complexity

The transition from **legacy medical supply chain systems to blockchain** requires **significant changes in IT infrastructure and operational workflows**, making adoption **challenging for organizations unfamiliar with blockchain technology** [22].

A study in [23] found that **stakeholder reluctance**, particularly among suppliers and healthcare providers, arises due to **concerns over implementation costs, lack of technical expertise,**

and perceived complexity. Additionally, the **interoperability of blockchain with existing enterprise resource planning (ERP) systems** remains a significant hurdle [24].

7.4 Initial Setup Costs and Investment Requirements

Implementing blockchain technology involves **substantial initial investments** in **network infrastructure, software development, and workforce training**. Research in [10] states that **deployment costs, including hardware procurement and security protocols, can deter small-scale medical suppliers from adopting blockchain**.

Furthermore, **ongoing maintenance and operational costs** must be considered, as blockchain networks require **continuous monitoring, updates, and security enhancements** to remain efficient and compliant [15].

Despite these challenges, research suggests that **long-term benefits such as cost savings, fraud prevention, and efficiency improvements** outweigh the initial implementation barriers, making blockchain **a viable long-term solution for medical supply chains** [17].

8. CONCLUSION

Medical supply chains face major challenges, including **overproduction, shortages, counterfeiting, and inefficiencies in tracking shipments**. Traditional systems often fail due to **lack of transparency, delayed data updates, and reliance on intermediaries** [9]. These problems became more evident during global crises like the COVID-19 pandemic, where some regions suffered severe shortages while others had surplus medical supplies that went to waste [12].

Blockchain technology offers a **reliable and secure solution** by **ensuring transparency, automating transactions, and enabling real-time tracking**. Through **decentralization, immutability, and smart contracts**, blockchain removes the need for middlemen and ensures that medical supplies are efficiently distributed where they are needed most [14].

However, **implementing blockchain in medical supply chains is not without challenges**. Legal regulations, technical barriers, and high initial costs make it difficult for widespread adoption [16]. Scalability issues and resistance from stakeholders also slow down the transition from traditional systems [18]. Despite these challenges, studies suggest that **the long-term benefits of blockchain—such as cost savings, fraud prevention, and waste reduction—outweigh the implementation difficulties** [20].

As the healthcare industry moves towards **more digital and automated systems**, blockchain is expected to play a key role in **creating a secure, efficient, and sustainable medical supply chain**. Future improvements, including **AI-driven demand forecasting and IoT-based tracking**, could further enhance its effectiveness [22]. By overcoming current obstacles, blockchain can **revolutionize medical logistics and ensure a more reliable supply of essential healthcare products** [24].

9. SDGs ADDRESSED

Blockchain-based medical supply chain solutions align with the United Nations' **Sustainable Development Goals (SDGs)** by promoting **responsible resource management, reducing waste, and improving healthcare logistics**. Specifically, this system supports:

9.1 SDG 12: Responsible Consumption and Production

SDG 12 emphasizes **sustainable management of resources and reduction of waste**. In traditional supply chains, medical supplies are often **overproduced, misallocated, or wasted**, leading to financial losses and environmental harm [9]. Blockchain helps address this by **improving demand forecasting, ensuring transparent tracking, and automating inventory management**, which prevents overstocking and ensures efficient distribution [12].

Additionally, blockchain can **facilitate the redistribution of near-expiry medical products** to locations where they are needed most, minimizing unnecessary disposal [14]. By enhancing supply chain efficiency, blockchain **reduces medical waste and promotes sustainability** in the healthcare sector [16].

9.2 SDG 15: Life on Land

SDG 15 focuses on **protecting ecosystems and reducing pollution**, which is directly impacted by improper medical waste disposal. Studies indicate that **medical supply waste, including expired drugs and single-use medical tools, contributes to soil and water contamination**, affecting wildlife and human health [18].

Blockchain mitigates this issue by **tracking product lifecycles and ensuring responsible disposal or repurposing of expired materials** [20]. Additionally, blockchain-powered auditing helps **enforce stricter environmental compliance** by providing regulators with tamper-proof records of waste management practices [22].

By addressing these SDGs, blockchain contributes to **a more sustainable, transparent, and efficient healthcare system**, reducing environmental damage and improving access to essential medical supplies [24].

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11. APPENDIX

The following QR Code redirects to a drive folder that contains video presentation, abstract of the report.

Note: Please use the following link in case of failure to scan QR Code

https://drive.google.com/drive/folders/1-3TCHiUMBy8lK-UGjy13kR0oqT-jwY8A?usp=sharing