BLOCKCHAIN REVOLUTION: TRANSFORMING THE PHARMACEUTICAL SUPPLY CHAIN IN BANGLADESH

BY

RUDRO SAHA
ID: 201-15-14040

FINAL YEAR DESIGN PROJECT REPORT

This Report Presented in Partial Fulfillment of the Requirements for the Degree of Bachelor of Science in Computer Science and Engineering

Supervised By

MUSHFIQUR RAHMAN
Lecturer (Sr. Scale)
Department of Computer Science and Engineering
Daffodil International University

Co-Supervised By

Ms. SHARUN AKTER KHUSHBU
Lecturer (Sr. Scale)
Department of Computer Science and Engineering
Daffodil International University

DAFFODIL INTERNATIONAL UNIVERSITY

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APPROVAL

This Project titled "**Blockchain Revolution: Transforming The Pharmaceutical Supply Chain in Bangladesh**", submitted by **Rudro Saha** to the Department of Computer Science and Engineering, Daffodil International University, has been accepted as satisfactory for the partial fulfillment of the requirements for the degree of B.Sc. in Computer Science and Engineering and approved as to its style and contents. The presentation has been held on **14th July 2024**

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Lecturer
Department of CSE
Faculty of Science & Information Technology
Daffodil International University

14.07.2024

Dr. Abu Sayed Md. Mostafizur Rahman (ASMR) — **External Examiner**
Professor
Department of Computer Science & Engineering
Jahangirnagar University

DECLARATION

I hereby declare that this project has been done by me under the supervision of **Mushfiqur Rahman, Senior Lecturer, Department of Computer Science and Engineering, Daffodil International University**. I also declare that neither this project nor any part of this project has been submitted elsewhere for the award of any degree or diploma.

Supervised by:

Mushfiqur Rahman
Lecturer (Sr. Scale)
Department of CSE
Daffodil International University

Co-Supervised by:

Ms. Sharun Akter Khushbu
Lecturer (Sr. Scale)
Department of CSE
Daffodil International University

Submitted by:

Rudro Saha
ID: 201-15-14040
Department of CSE
Daffodil International University

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ABSTRACT

This study addresses the use of blockchain technology to enhance the pharmaceutical supply chain in Bangladesh, handling significant challenges including product quality and fake medicines. The analysis of the literature highlights the shortcomings of earlier research as well as the pressing need for improved supply chain authenticity and transparency. The main objective of the development of a blockchain-based system blueprint are selecting an appropriate blockchain platform, resolving supply chain problems with blockchain, and identifying particular implementation challenges in Bangladesh. The motivation of this research is to make the pharmaceutical system more transparent and trustworthy. In-depth literature reviews, supply chain blueprints, and the selection of a suitable blockchain platform based on key factors are all part of the research process. The results shows the comparison of different blockchain platform as well as highlights their potential benefits and implementation challenges to Bangladeshi pharmaceutical supply chain system to replace the existing system. This thesis is different from others because of it's comparative analysis of several blockchain platforms from the perspective of Bangladesh's pharmaceutical supply chain.

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CHAPTER 1
INTRODUCTION

1.1 Overview

Blockchain is an innovation that can change the society in the midst of the installation of affirmation, transparency, traceability, and trust. An important aspect of the health service sector is the pharmaceutical supply chain. Lately, the pharmaceutical supply chain of Bangladesh has shown good success. But it also has some limitations that blockchain technology can play an important role in solving. The Bangladeshi government also acknowledges it as a crucial element in the fast expansion of modern technology. The pharmaceutical supply chain has shown excellent outcomes in the local market, however, system upgrades have to be ensured to offer transparency, efficiency, and growth in the global market.

1.2 Background and Present State

The current pharmaceutical supply chain faces many challenges due to its complex structure. Its transparency and traceability at the global level are repeatedly questioned due to its central dependence. The supply chain has faced numerous challenges over the years, such as counterfeit drugs, product recalls, and ineffective supply chains. These issues have the potential to compromise patient safety and threaten the integrity of the pharmaceutical market. If this keeps happening, our native people will lose trust in our medicine, and even if it is still available locally, their lack of authenticity will make them dependent on outside sources. The issues in our current pharmaceutical supply chain will be responsible for this.

Due to the decentralized, transparent, and secure qualities of blockchain technology, various researchers have suggested applying it to the pharmaceutical supply chain. This can offer us a reliable and safe system for ensuring the authenticity and transparency of drugs. Before building this system, it will be easier if we discuss in detail the advantages and disadvantages of different platforms of blockchain technology. This thesis analyzes the potential application of blockchain technology in the pharmaceutical supply chain in Bangladesh, focusing on the specific needs and barriers facing the pharmaceutical sector. An overview of the problem statement, a discussion of the motivation behind the research, and an explanation of the objectives of the study will be included in this introduction.

1.3 Problem Statement

According to WHO, more than 30% of medicine in some countries is fake, which is seriously harmful to patient's health. These problems stem from inadequate tracking and tracing capabilities of existing supply chains.

Because it provides essential medicines to individuals around the world, the pharmaceutical industry is a significant contributor to public health. Drug reliability, safety and availability are threatened by a number of issues that the pharmaceutical supply chain must address. Among these issues are counterfeiting, inefficiencies in operations, insufficient transparency, and susceptibility to disruptions. The general health, patient safety, and trustworthiness of the healthcare system are all affected by these issues.

Failing to choose the appropriate blockchain platform may be one of the primary causes of these issues. Hyperledger Fabric and Ethereum have received a lot of attention in previous research, but other blockchain platforms like IBM Blockchain, Openport, and VeChain have not been examined. Once more, it is concerning that Proof of Authority is not discussed in the context of the consensus algorithm. The difference is critical since PoA might have a unique impact on supply chain security and transparency.

Furthermore, there are frequently insufficient guidelines in the literature for creating decentralized applications (dApps) that are specifically designed for the pharmaceutical industry in Bangladesh. Identification of particular local difficulties and potential obstacles to blockchain integration, such as interoperability with digital infrastructure and regulatory compliance, is required.

1.4 Objective

The purpose of this thesis is to address the challenges faced by the pharmaceutical supply chain in Bangladesh through the application of blockchain technology. This study aims to achieve the following objectives:

1. Blockchain Technology Assessment: Reducing Use of Counterfeit Medicines and Ensuring Authenticity. Through which blockchain technology can be used to ensure the security and transparency of the supply chain.
2. Supply Chain Problem Solving: Through the application of blockchain technology, the problems faced by the pharmaceutical supply chain in Bangladesh can be tackled and the authenticity and quality of medicines in the hands of patients can be ensured.

3. Blockchain Platform Analysis: Security, Transparency, Traceability, Scalability, Consensus Algorithm To evaluate different platforms of blockchain technology to find the best one for pharmaceutical supply chain based on some features.
4. Creating a Blueprint: Creating a transparent blueprint that can be used to build a blockchain-based system that meets the specific requirements of the pharmaceutical supply chain in Bangladesh.
5. Proposing solutions for implementation challenges: All the problems that may arise during the implementation of blockchain technology such as: Stakeholder acceptance and current technological infrastructure. So as to provide a realistic outline with consistency.

This thesis explores the research gaps and transforms the pharmaceutical supply chain in Bangladesh through blockchain technology to provide a practical framework for system development and implementation.

1.5 Scope and Limitations

This study, focused on how blockchain technology can improve the pharmaceutical supply chain in Bangladesh. Aim to understand the basics of blockchain, look at the current supply chain and find ways to make it better using blockchain. Here comparison of different blockchain platforms will happen to see which one is best for our needs. Additionally, And a plan will be created for implementing blockchain in the pharmaceutical supply chain and conduct a small test to see how well our ideas work.

Our scope includes understanding blockchain technology, examining the current state of the pharmaceutical supply chain in Bangladesh and proposing a blockchain-based framework to address the challenges we find. A comparative analysis of different blockchain platforms will conduct to determine the most suitable one for our needs. Finally, the process of testing and evaluating the proposed blockchain solution will be discussed.

However, this study has some limits. We only look at the pharmaceutical supply chain in Bangladesh, so our findings might not apply to other places. The technology we need might not be fully available in all areas of Bangladesh. There might also be legal and regulatory issues haven't covered in detail on this study. Constraints have been faced with the resources available for this project, which might affect the comprehensiveness of the test. Additionally, the quality and availability of data might limit this study, as we rely on existing data from the pharmaceutical supply chain in Bangladesh.

Despite these limitations, this study aim to provide a clear understanding of how blockchain can help improve the pharmaceutical supply chain in Bangladesh. It will offer valuable insights and a practical framework for implementing blockchain technology in this critical sector.

1.6 Report and Organization

This report is divided into different parts to get a clear and comprehensive idea about the different parts of the research

- In Chapter 1, it provides the background study, background information, state the problem are addressed, explain the objectives and discuss the scope and limitations of this research.
- In Chapter 2, it reviews existing literature, compare their findings and identify any gaps or open issues.
- In Chapter 3, here the methodology have been described including the system design, list of the hardware and software requirements and project management.
- In Chapter 4, discuss about the development process, the design of the prototype and testing and evaluation method.
- In Chapter 5, it presents the results and analysis we have share our findings, compare this system with existing solutions and discuss the implications of the results.
- In Chapter 6, it explores the impact of this work on society, the environment, and sustainability. Will discuss about how blockchain technology can improve drug safety and accessibility and consider the ethical aspects.
- In Chapter 7, here the study concludes and suggests future work. It summarize the key findings, discuss the contributions of this research and propose areas for further investigation.

In this study each chapter helps to get knowledge about blockchain technology and it’s use case in pharmaceutical supply chain.

1.7 Summary

The summary of this report encapsulates the primary objectives, methodologies, and findings. It highlights the significant insights gained from the research, providing a concise overview of the major contributions of the study. The challenges encountered during the research process and the solutions proposed are also briefly discussed. This section serves as a quick reference for readers to understand the essence of the entire report.

CHAPTER 2
LITERATURE REVIEW

2.1 Overview

Here the focus is on the Bangladeshi pharmaceutical supply chain as it is identified as one of the vital sectors of economic growth and public health by the Bangladesh government. Many reports say that it is already a successful sector in our local market. But now, to grow this market to an international level, we need to maintain a standard. That is why the system needs to be upgraded to improve the transparency & safety of the drugs, focusing on decentralized distribution as recommended [1].

2.2 Related Works

The traditional supply chain faces many issues, like it can’t ensure drug authenticity [2]. There are reports of fake drugs being sold as genuine, along with genuine drugs imported from developed countries [3]. As 97% of drugs are produced by local companies [9], it should indicate a strong pharmaceutical industry, but research shows that within five thousand drugs, three hundred are counterfeit [10]. As a result, customers are always concerned. Sometimes products are produced without maintaining quality control in order to meet high demand [7]. It is clearly shown in various articles that the current system has some errors, like transparency and traceability, that need to be fixed. It is shown that blockchain technology has the potential to reduce these errors through security improvements and lower transaction costs [4]. Also, the flexibility of blockchain to integrate with existing technology can help with better recall, shortage, and counterfeit control [5]. Here, counterfeiting is a major problem, and the author has suggested a blockchain system that makes use of the Hyperledger Fabric technology [2]. According to the World Health Organization (WHO), approximately 30% of the drugs sold across 140 countries are believed to be counterfeit, worth $250 billion per year [8, 11]. With an estimated yearly worth of over US$600 billion, counterfeiting has emerged as one of the biggest and fastest-growing criminal businesses in the world, according to the International Anti-Counterfeiting Coalition (IACC) [12]. It indicates that a significant amount of counterfeit drugs are sold and taken in areas where healthcare resources and regulatory oversight may be limited, which further increases the risks to public health. A study reveals that the pharmaceutical industry's main goal is to prevent the sale of counterfeit drugs [15]. Blockchain technology can help overcome the challenge when it comes to payments in the context of e-commerce [17]. Many authors have identified that blockchain technology can change scenarios in many ways. A blockchain-based solution was created using a framework by the author in [13] to fight with counterfeit drugs by ensuring authenticity and traceability. Blockchain technology can safeguard the pharmaceutical industry, but its not sure that which platform is appropriate for. A blockchain based system helps the stakeholders including patients to trace and authenticate the medicine [2]. To achieve that, author [2] have chosen Hyperledger Fabric without any justification. According to the author [14], Hyper Ledger's technology was more suitable for its robustness in handling transaction security and providing pluggable consensus options [2]. But, Vechain, which is excellent for supply chains, was not talk about. Another system architecture may be seen in [16], where a supply chain model utilizing ganache, a local Ethereum blockchain, is suggested. It's a good setting for developing and testing dApp’s. However, the dApp's blueprint was missing from that location. However, other platforms like Ethereum and VeChain also offer unique advantages that could be more suited to the specific needs of the supply chain. For instance, Ethereum's strong support for smart contracts makes it ideal for automating supply chain processes and ensuring compliance [11]. On the other hand, VeChain's Proof of Authority consensus mechanism offers a balance between centralized control and decentralized operations, which can be advantageous for maintaining high-security standards in pharmaceutical logistics [11].

Based on how to reach consensus Blockchain's performance have differences. The consensus algorithm performs the crucial role of ensuring a block's security and validity [19]. Here, the author has reviewed several methods for achieving consensus and provided a comparative analysis of consensus algorithms. Consensus algorithm performance is crucial when choosing a platform because it determines the throughput, mining profitability, level of decentralization, and overall security of the blockchain. These details were presented clearly and concisely in [20], but there was a lack of information on a consensus technique called "Proof of Authority" that is used in VeChain. Proof of authority works well in public and private networks [18]. However, scalability problems with both public and private blockchains are frequently brought up, and in order to address these problems, sometimes a feature must be given up. For example, the Hyperledger fabric gave up decentralization in order to increase scalability [25].

According to a comparison table in [5], the VeChain blockchain is less difficult to integrate with than the Hyperledger and Ethereum blockchains. More significant insights like this one, including comparisons of transaction and block confirmation times, and many more, are provided in this article and are highly beneficial when selecting a platform for a decentralized application. Problems with other platforms are covered in [20], which also mentions the Ethereum and Hyper Ledger blockchains in addition to the IBM blockchain technology. Hyperledger Fabric has been found to have more advantages than alternative blockchain frameworks for decentralized apps, according to a thorough evaluation [21]; yet, the selection of a platform is dependent upon the specific requirements of the use case. These kinds of studies will be very helpful in the platform selection process.

In [22], a number of difficulties found while implementing blockchain solutions are listed along with their sources. Some of these difficulties include IOT validation rules, legal concerns, technological challenges, etc. Before developing a blockchain-based system in any nation, these issues must be kept in consideration. Acquiring above 50% of the network's hashing power poses a risk to the consensus algorithms in both public and private blockchains [23]. One major problem is getting everyone to agree on what information to share and with whom [24].

2.3 Comparison between existing works

In this part, we compare different studies on using blockchain in the pharmaceutical supply chain. Some researchers have focused on using Hyperledger Fabric [2], which is good for permissioned networks and offers high privacy. Others have looked at Ethereum, which is well-known for its smart contracts and public accessibility [11].

One study shows that Hyperledger Fabric is great for secure and private transactions but can be complicated to set up [14]. Another study highlights that Ethereum is more flexible with its smart contracts, making it easier to automate processes. However, Ethereum can be slower and more expensive due to high transaction fees.

Some researchers have also considered VeChain, which uses the Proof of Authority (PoA) consensus mechanism [11]. VeChain is efficient and has low transaction costs, but it is less decentralized compared to other platforms.

We found that while all these platforms have their strengths, they also have limitations. Hyperledger Fabric is best for privacy, Ethereum excels in flexibility, and VeChain is efficient but less decentralized. By comparing these studies, we can better understand which platform might be best for improving the pharmaceutical supply chain.

2.4 Open Issues

Even though blockchain can improve the pharmaceutical supply chain, we still have some issues to address. One issue is scalability because blockchain networks can struggle with many transactions at once. We also need to integrate blockchain with our current systems, which can be complex and costly. Data privacy and security are other concerns. While blockchain is secure, we must ensure that sensitive information stays private. Regulatory compliance is also challenging since the pharmaceutical industry has many rules that our blockchain solutions must meet. The cost of setting up a blockchain system is high, including technology, training, and infrastructure updates. We need everyone in the supply chain to accept and trust the technology, which can be difficult. We also need technical expertise to develop and manage blockchain systems, but skilled professionals are in short supply. Lastly, ensuring that different blockchain platforms can work together smoothly is necessary for a unified supply chain. We need to address these issues to use blockchain technology successfully in the pharmaceutical supply chain. More research and development will help us overcome these challenges and fully benefit from blockchain.

2.5 Summary

After reviewing many papers about this topic, lots of information has been gathered and analyzed, which will be used for this work. However, there are still gaps to be addressed, such as i) the reasons behind selecting a blockchain platform (research on this subject has been conducted, but it was discovered that the focus was mostly on Hyper Ledger and Ethereum, with less attention focused on the Vechain and IBM blockchain platforms), ii) while proof of work and proof of stake have been extensively compared and discussed, proof of authority must also be done so. iii) While system architecture was included, the actions involved in creating a dApp for testing and development were not thoroughly addressed in detail; instead, the majority of authors talked about how they would implement a solution.

CHAPTER 3
METHODOLOGY

3.1 Overview

The process of controlling the movement of products and services into and out of a company, including each stage involved in transforming raw materials and component parts into finished items and delivering them to the final consumer, is known as supply chain management. There are several related steps involved.

- Supplier: This process begins with the supply of raw materials required to manufacture the product. Quality control is mandatory here.
- Manufacturer: Manufacturers: Manufacturers turn the raw materials from suppliers into final products. This step is very important to make sure the products fulfill the prerequisites.
- Warehouse & Inventory Management: Products are kept in warehouses when they are manufactured. At this point, inventory control is essential to maintaining a balance between supply and demand, avoiding stockouts or overstocking, and lowering storage expenses.
- Distribution: Transporting goods from warehouses to retailers or straight to consumers requires logistics procedures at this point. This must be done in a secure way so that no counterfeit product can enter.
- Retailer: At this point, the products are finally made available to customers. This could apply to pharmacies, healthcare facilities, and hospitals in the pharmaceutical industry.
- Consumers: Product Reaching the customer, who makes the purchase and consumes it, is the supply chain's end.

Bangladesh's pharmaceutical industry is rapidly growing, contributing significantly to the country's GDP and employment generation. With over 250 registered companies, key players like Beximco Pharmaceuticals Ltd., Square Pharmaceuticals Ltd., and Incepta Pharmaceuticals Ltd., are setting quality standards and expanding their reach globally. The industry's growth has improved the country's trade balance, reducing imports and increasing exports. The industry's ability to produce affordable medicines has improved healthcare outcomes and made healthcare more accessible. This thesis explores the application of blockchain technology to enhance the pharmaceutical supply chain, aiming to address challenges and enhance efficiency, reliability, and trust in the sector.

3.2 Proposed Methodology

3.2.1 Current System Analysis

Traditional supply chains operate in a simple, linear, or sequential manner. As a result, it occasionally has problems with high inventory costs, problems with real-time data exchange, and supply chain tracking and tracing. Relying on manual processing may result in delays and inefficiencies. Due to some flaws in the existing system, such as a lack of transparency, it is easier for counterfeit drugs to get onto the market. The entire process is inefficient and slow due to poor traceability. Because the supply chain lacks traceability and control, it is unable to meet demand, resulting in losses and additional costs.

There is a need to transform the Bangladeshi pharmaceutical supply chain into a blockchain based supply chain to upgrade systems, maintain international standards and establish trust between consumers and stakeholders. Implementing important elements such as tracing, tracking and security in this complex existing system will not be easy at all. Bangladeshi pharmaceutical supply chain involves many stakeholders, big and small, so it is necessary to come up with a solution that will control the quality of medicine and be secure and efficient. The use of this technology may present some difficulties, for which we must prepare and provide the necessary training.

3.2.2 Finding System Breach

Manual or paper-based pharmaceutical supply chain tracing and tracking systems are not effective. This makes it largely impossible to detect counterfeit drugs, which endangers patient health and challenges our healthcare system. Exploiting this weakness in the supply chain, many counterfeit drugs are entering the market containing dangerous chemicals and improper dosages. According to the data of WHO, about 30 percent of fake medicines are supplied to the underdeveloped countries of the world including Bangladesh. These problems in Bangladesh have become serious as the general population is more dependent on easy and fast acting drugs. Widespread use of counterfeit drugs is undermining public confidence in the medical sector.

Shortcomings in the Pharmaceutical Industry

- Lack of transparency and traceability in existing supply chains makes it easy for counterfeit drugs to enter the market.
- If there is a problem with a particular batch of a drug, it is difficult to find it and withdraw it from the market

- Lack of access and control over the entire supply chain can make ensuring compliance with regulatory standards challenging

3.2.3 Understanding Blockchain Fundamentals

Blockchain technology is a revolutionary innovation like the Internet that makes communication more secure by ensuring trust and transparency. It is a transparent system with distributed and immutable ledger where data is stored across thousands of servers worldwide. This distributed system gives all participants full access to the system's database and history.

Blockchain is basically a type of digital chain where data is made up of a series of blocks that are linked in sequence. Transaction history is stored in each block of this chain. These transactions are validated and connected to previous blocks through a cryptographic hash that ensures the integrity and continuity of the transaction history like a unique fingerprint. This unique connection mechanism of blockchain makes it secure because changing the data in any one block requires recalculating the cryptographic hashes of all subsequent blocks, which is impractical without the participation of more than half of the participants in the network.

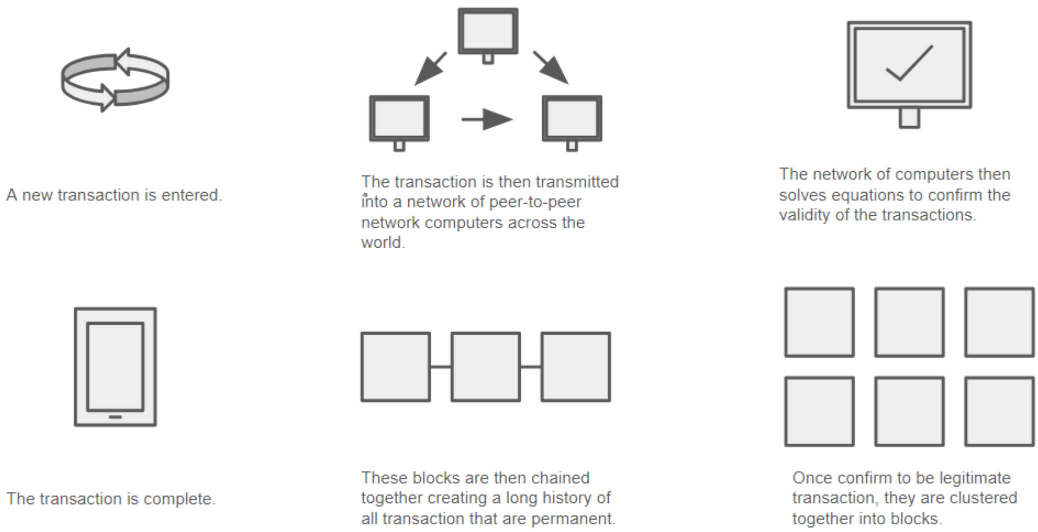

Figure 3.1: Blockchain System

Key Features of Blockchain:

1. Decentralization: Blockchain works on a peer-to-peer basis with no central dependency, which can ensure a better supply chain by reducing the risk of centralized control and data manipulation.

2. Immutability: Once a data record is recorded on the blockchain, it cannot be changed without altering all subsequent blocks and without the consent of all participants across the network, making blockchain highly secure, an essential quality for maintaining accurate records of product origin, production and distribution within a supply chain.

3. Transparency: All the transactions recorded on the blockchain are visible to all participants, which enhances transparency and builds trust among consumers and stakeholders. These ensure the quality and authenticity of the drug throughout the supply chain.

4. Security: The use of cryptographic hashing and consensus mechanisms increases the security of blockchain technology, making it nearly impossible to illegally alter data.

Elements of Blockchain:

1. Distributed Ledger Technology (DLT): Distributed Ledger Technology is a decentralized digital system that refers to the protocols and technical framework that enable concurrent record update, validation, and access throughout a networked database. It underpins blockchain's ability to enhance supply chain management by eliminating the central point of failure inherent in traditional systems. Instead of storing data in a single location in a blockchain, it is distributed among all the computers in a network where each holds an identical copy, ensuring that the system remains operational even if one part of the network fails. By storing transaction history simultaneously in multiple locations, it is providing a robust mechanism against data manipulation The immutable and transparent nature of DLT allows products to be traced and authenticated with unparalleled accuracy, which is critical to maintaining security and compliance within the supply chain.

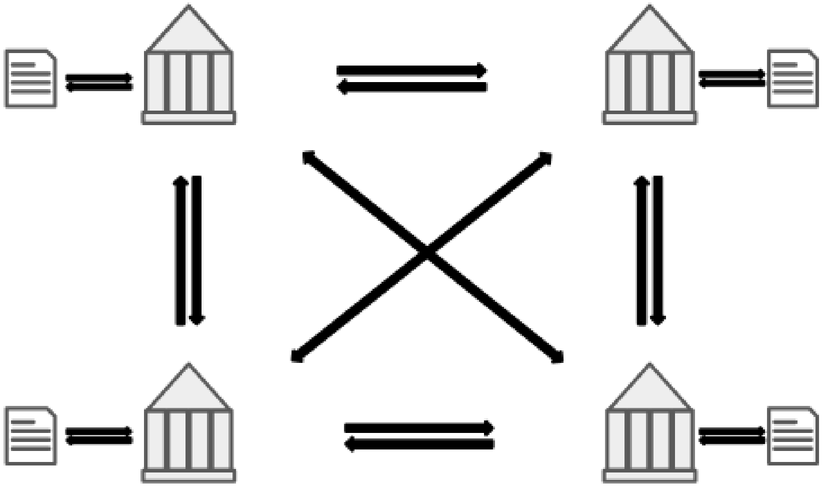

Figure 3.2: Distributed Ledger

2. Smart Contracts: Smart contracts transform supply chain processes by converting commercial agreements into programmable structures that take automatic action upon fulfilling specific requirements. There's no need for intermediary oversight when these contracts work, which lowers the likelihood of disputes and mistakes. Smart contracts can improve supply chain efficiency and dependability by automating tasks like payment and receipt after product verification. The clear, unambiguous records of transactions provided by these contracts' automation and transparency reduce execution delays and build trust among all parties.

3. Consensus Mechanisms: Consensus mechanisms play an important role in validating blockchain transactions, maintaining integrity and securing the distributed ledger, which ensures that data is nearly impossible to alter without the consent of all participants in the network. Which is a must-have feature for supply chains where storing product details is critical Various consensus mechanisms, such as Proof of Work, Proof of Stake, and Proof of Authority, offer different balances between security, efficiency, and speed, influencing their suitability for specific applications in supply chain management. The choice of consensus mechanism is critical, affecting everything from transaction throughput to network scalability, and must be aligned with the specific needs of the supply chain to ensure optimal performance.

Types of Blockchain

1. Public Blockchains: They are fully decentralized and open to anyone to participate, making them highly transparent but also slow transactions due to their size and required consensus process. Although they offer the highest

level of transparency, public blockchains may not be suitable for all supply chain applications due to privacy concerns and scalability issues.

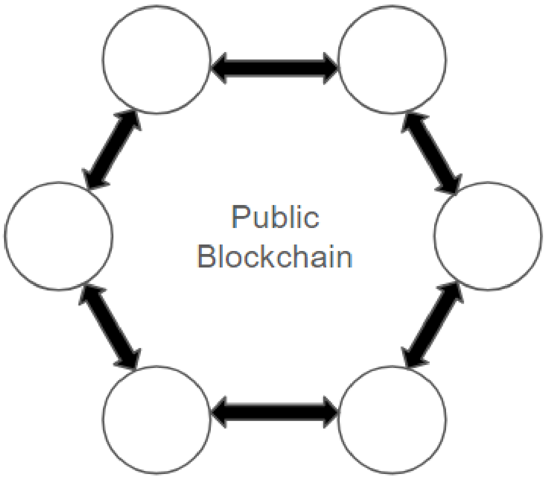

Figure 3.3: Public Blockchain

2. Private Blockchains: Private blockchains controlled by a single entity offer greater control over participation and are more efficient in transaction processing. It can be ideal for supply chains because it prioritizes faster transaction processing and privacy, but it has a drawback that it offers less transparency than public blockchains.

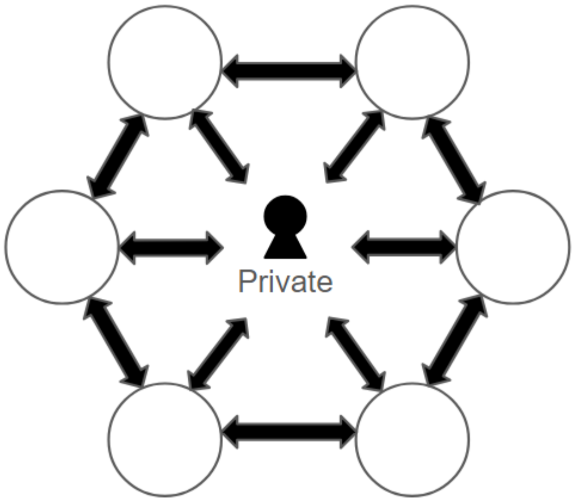

Figure 3.4: Private Blockchain

3. Consortium Blockchains: It is controlled by a group of organizations that strike a balance between the public blockchain's decentralized nature and the efficiency of the private blockchain. It can be preferable for the supply chain because multiple stakeholders can operate efficiently and securely while maintaining privacy.

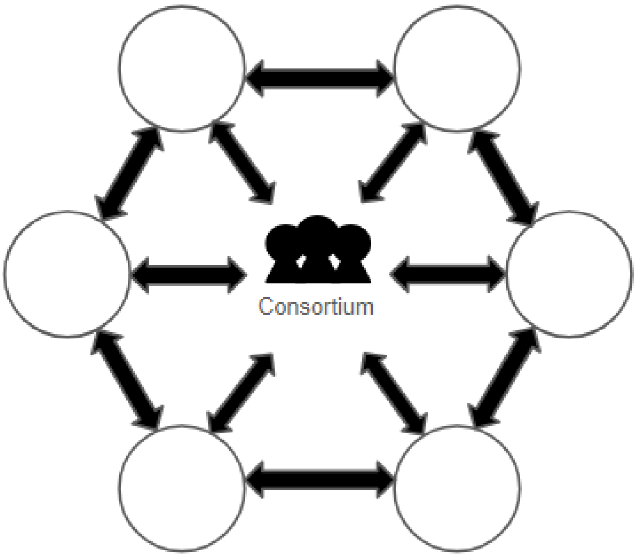

Figure 3.5: Consortium Blockchain

3.2.4 Analysis of Blockchain Platforms and Consensus Mechanisms

In the context of my thesis having Knowledge of various blockchain platforms is a must. Therefore, this section provides a descriptive and comparative discussion of various blockchain platforms and consensus algorithms.

Hyperledger Fabric: Hyperledger Fabric is a permissioned blockchain designed to be very flexible for enterprise applications. Its pluggable consensus mechanism allows the use of different consensus mechanisms based on the specific requirements of the network and by default it uses Practical Byzantine Fault Tolerance (PBFT). PBFT is a proven consensus algorithm known for its Byzantine fault tolerance in a network. Based on specific requirements, some other consensus mechanisms are used. As Raft Consensus is a simple crash-tolerant consensus algorithm designed for use in peer networks. And while Kafka Orderer is not suitable for production environments due to its single-node nature, Solo Orderer can be used for development or testing purposes. The choice of consensus mechanism in Hyperledger Fabric depends on factors such as the network's trust model, scalability needs, privacy requirements and the required level of fault tolerance. Its modular architecture and support for various consensus mechanisms make it a versatile framework suitable for diverse enterprise blockchain applications.

It's channel-based design keeps transactions separate between channels and no one except the authorized user can access the data which increases privacy. These qualities are very helpful for the supply chain as every data and formula needs to be kept accurate. Some of the advantages of Hyperledger Fabric include low latency, high transaction, modularity, scalability. But being a permissioned network, it cannot achieve the same level of decentralization as a public network, which can be considered as one of its drawbacks. This framework supports languages like Go, Java and Node.js for development purpose.

Ethereum Blockchain: Ethereum pioneered smart contract development that currently uses the Proof of Work (PoW) consensus mechanism but is set to upgrade to Proof of Stack (PoS) with the release of Ethereum 2.0. This shift is to overcome the scalability and energy consumption issues of Proof of Work. And this upgrade to Proof of Stack will increase network capacity, reduce transaction costs, reduce environmental impact, make it more environmentally friendly, and enable complex dapps development and management.

Ethereum's smart contract functionality is beneficial for advanced decentralized application development to automate difficult supply chain tasks such as real-time drug tracking and tracing, verification and automatic payments. Ethereum's smart contract development uses the solidity language, which is similar to C++. Along with the advantages, Ethereum blockchain also has some disadvantages such as high transaction cost and scalability issues which will be solved through PoS upgrade. It increases transparency due to its public nature but remains a privacy concern when sensitive data is handled.

VeChain: VeChain is perfect for supply chains that enable scalability and efficiency. Its use of Proof of Authority consensus mechanism makes transaction validation fast and cost effective which is validated by approved accounts. Its 2 important features are high scalability and low transaction costs required for supply chains that do not require extensive computational power and energy to achieve. Here speed and efficiency are more important than decentralization

On the other hand, the centralized behavior of PoA can lead to network security and neutrality issues, which only grant network control to certain validating nodes. While decentralizing the network requires the participation of all nodes, relying on only a few nodes can expose users to risks such as censorship and data manipulation that affect the security and neutrality of the network. Like Ethereum it also uses Solidity programming language to build efficient and low transaction cost applications.

IBM Blockchain: The IBM blockchain is based on the Hyperledger Fabric which provides a pluggable consensus mechanism. It is a commercial deployment of hyperledger fabric for business applications that are suitable for industries such as banking, healthcare and pharmaceuticals. The main focus of IBM Blockchain is privacy, security and scalability. It provides features like privileged membership through which only authorized members can participate in the network and exchange data, which creates a more secure environment. Also enhances performance scalability and data protection. IBM's platform is particularly known for its strong emphasis on collaborative workflows.

But due to its permissioned nature, it offers drawbacks similar to Hyperledger Fabric. However, it may be suitable for pharmaceutical supply chain because of its strong governance, high data privacy, scalability and convenience in sensitive data handling. It supports languages like JavaScript, TypeScript, Go and Java, which facilitates developers for different systems.

Comparison Between Consensus Algorithms: Here is the comparison between PoA, PoS, and PoW consensus algorithms based on my thesis pharmaceutical supply chain to decide which one is better.

Table 3.1: Comparison of consensus algorithms

Feature	Proof of Work (PoW)	Proof of Stake (PoS)	Proof of Authority (PoA)
Consensus Process	Miners solve complex mathematical problems to validate blocks	Validators are chosen based on the number of coins they hold	Validators are pre-selected and trusted entities in the network
Energy Consumption	Very high due to the computational intensity	Much lower as it does not require intensive computation	Low, as it relies on identity as a stake rather than computation
Transaction Speed	Slow due to the time needed to solve puzzles	Faster than PoW as it relies on stake rather than computation	Very fast, as only a few trusted nodes validate transactions
Scalability	Limited scalability due to high energy costs and slow block times	Better scalability due to less computational overhead	High scalability as it avoids complex algorithmic solutions
Decentralization	High, as any participant can become a miner	Less decentralized as the richest have more control	Low, as only a few pre-selected nodes have control
Security	High, as altering the blockchain requires significant computational	Moderate, risks include nothing-at-stake problem	Lower, potentially vulnerable to insider threats as a few nodes

	power		control the consensus
Suitability	Suitable for networks that prioritize security and decentralization	Suitable for networks that need speed and energy efficiency	Ideal for private networks where trust is established among validators
Complexity	Technically complex and requires significant computational resources	Less complex than PoW, easier to participate for holders	Least complex, requires a trusted central authority

3.2.5 Appropriate Platform Selection

In this part of the study, different blockchain platforms are compared through a comparison table.

Table 3.2: Comparison of different blockchain platform

Feature	**Hyperledger**	**Ethereum**	**VeChain**	**IBM Blockchain**
Cryptocurrency	None	Ether (ETH)	VeThor Token	None
Smart Contract	Yes	Yes	Yes	Yes
Update Frequency	Quarterly	Frequently	Frequently	Varies
Security Model	Membership-based, permissioned	Public, not encrypted	Block security, public	Permissioned
Block Time	Varies	~15 seconds	Faster	Varies
Type	Permissioned	Public/private	Public	Permissioned
Scalability	1,000 TPS	15 TPS (improving with ETH 2.0)	50-10,000 TPS	Varies
Developer Team	Large	Large	Large	Large

Transaction Time	Varies	Moderate	N/A	Varies
Integration	Varies	Difficult	Easier	Depends
Interoperability	High (with other Hyperledger tools)	Moderate (improving with updates)	Moderate	High (within IBM products)
Privacy	Channels for private transactions	Layer-two solutions for privacy	Transaction controllability	Channels for private transactions
Consensus Mechanism	Pluggable (e.g., Raft, Kafka)	Proof of Work, moving to Proof of Stake	Proof of Authority	Pluggable (based on Hyperledger Fabric)
Suitability for Supply Chain	Excellent for controlled access	High customization for various needs	Excellent for product lifecycle management	Excellent for controlled access
Limitations	Less suitable for public networks	High gas costs, scalability issues	Lesser known, fewer implementations	High dependency on IBM infrastructure

Ethereum is superior to other blockchain platforms such as Hyperledger, VeChain, and IBM Blockchain when compared on a number of important elements related to the pharmaceutical supply chain. Scalability, integration complexity, developer support, and particular supply chain-enhancing capabilities like smart contracts and update frequency are the factors that this research is based on.

Scalability and Efficiency: With the introduction of sharding to increase network capacity and lower transaction fees, as well as a move to Proof of Stake, the Ethereum 2.0 upgrade is expected to greatly improve Ethereum's current transaction processing speed of roughly 15 transactions per second (TPS). Although VeChain's TPS range is high, Ethereum is more scalable and sustainable in the long run due to Ethereum's widespread adoption and ongoing progress.

Smart Contract Capabilities: Ethereum has the sophisticated and incredibly adaptable smart contract capabilities needed to automate complex processes in the pharmaceutical supply chain. These include instant payment verification after delivery, automated compliance checks, real-time tracking and quality assurance. This degree of automation can increase productivity and significantly reduce human error.

Developer Ecosystem and Support: Compared to platforms like VeChain, the enterprise-focused IBM blockchain, and Hyperledger Fabric, Ethereum has a large and robust development community, which is essential for continuous system maintenance and debugging. This large development base leads to extensive third-party tools and libraries that simplify maintenance and implementation.

Integration and Update Frequency: Despite its complicated and vast architecture, blockchain technology is always in the news due to its regular upgrades, enhancements and new features that are required to fulfill the demands of the pharmaceutical supply chain.

Security and privacy: Although Ethereum is a public blockchain, it has some powerful privacy capabilities such as layer-two solutions and zero-knowledge proof that enable better scalability and private transactions. These are very important to keep sensitive data private and confidential

An example would be if a pharmaceutical company needs to guarantee privacy and integrity in drug supply, then an Ethereum smart contract would be needed to automatically and securely track and trace from production to distribution. Here stakeholders can provide confirmation of pharmaceutical product handling without accessing sensitive information.

Platforms such as Hyperledger Fabric and IBM Blockchain provide specific features and privacy-focused capabilities. But the vast ecosystem and developer base of the Ethereum blockchain makes it most suitable for highly sophisticated smart contracts and privacy pharmaceutical supply chains. Ethereum's widespread adoption and regular technological advancements make it flexible and efficient, and can play an important role in solving difficult supply chain problems. Because of this, Ethereum is a perfect fit for modern pharmaceutical supply chain management, where efficiency, security, and transparency are important.

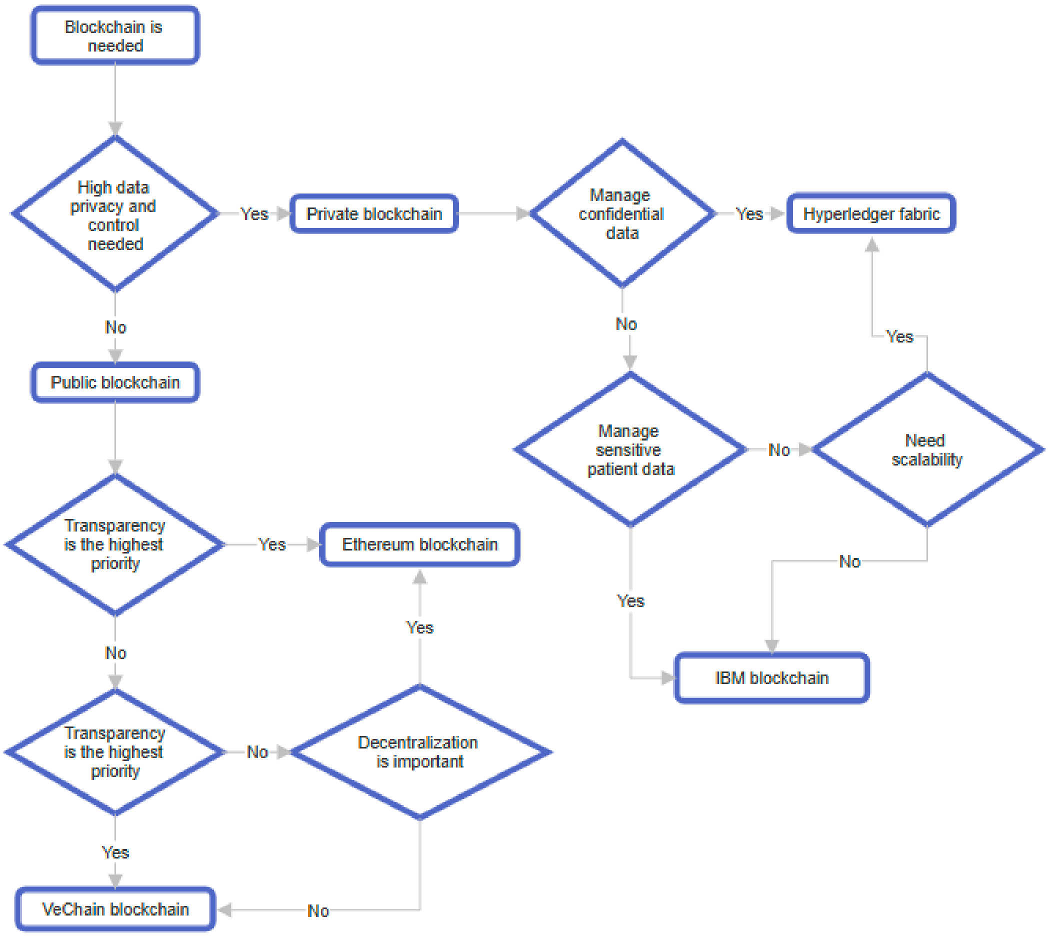

Figure 3.6: Platform selection flowchart

3.2.6 Reason For Switching to Blockchain

In a traditional web application, when it connects to the central server, all the data & source code become available in a central database, which leaves them vulnerable to many types of cyber-attacks. Here, an unauthorized user can alter or corrupt the data. Which can adversely affect our public health and our country's economy. And this cannot be allowed to happen. In addition, the limited visibility of stakeholders increases manipulation or errors. And the tracking and authenticity of drugs are complex here. So, due to this insecurity, we decided to implement blockchain in the pharmaceutical industry.

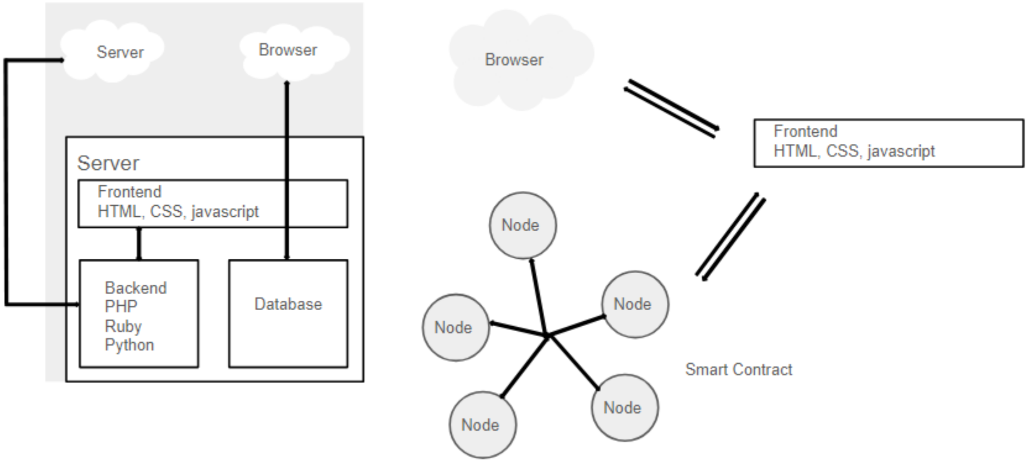

Figure 3.7: Traditional vs Proposed system

Blockchain does not have a centralized server. It is a network as well as a database system. It is a “peer to peer” system, which means all the computers connected to the network hold all the data and source code. It significantly increases security, transparency, and stakeholder trust.

To build this system, it combines the traditional front-end client side with the Ethereum blockchain. This front-end directly interacts with the local Ethereum blockchain. All the logic and smart contracts are written in solidity, which is immutable. Once it is implemented on the blockchain, it cannot be altered, which is important to ensure security.

3.3 Software Requirements

To implement the Ethereum blockchain in the pharmaceutical supply chain, an environment is required. An overview of the prerequisites.

1. Truffle: It is powerful tool for smart contract development with solidity on Ethereum blockchain, which comes with end to end development capabilities, security first approach, and smart contract management.

2. Node.js: It provides Node Package Manager, which is required for this system. It makes third party dependency management easier.

3. Ganache Test Net: Using Ethereum Test Net for testing purposes is not recommended. So I use Ganache, which is a local personal test network that acts like public blockchain.

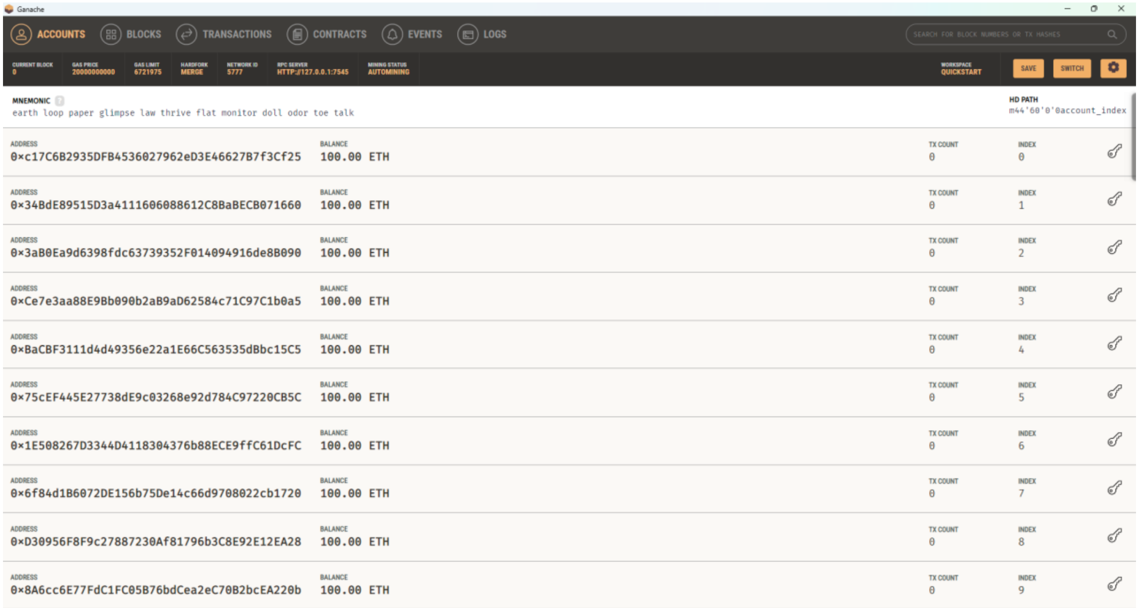

Figure 3.8: Ganache account list

4. Meramask: To connect users to this system, a Metamask browser extension is needed.

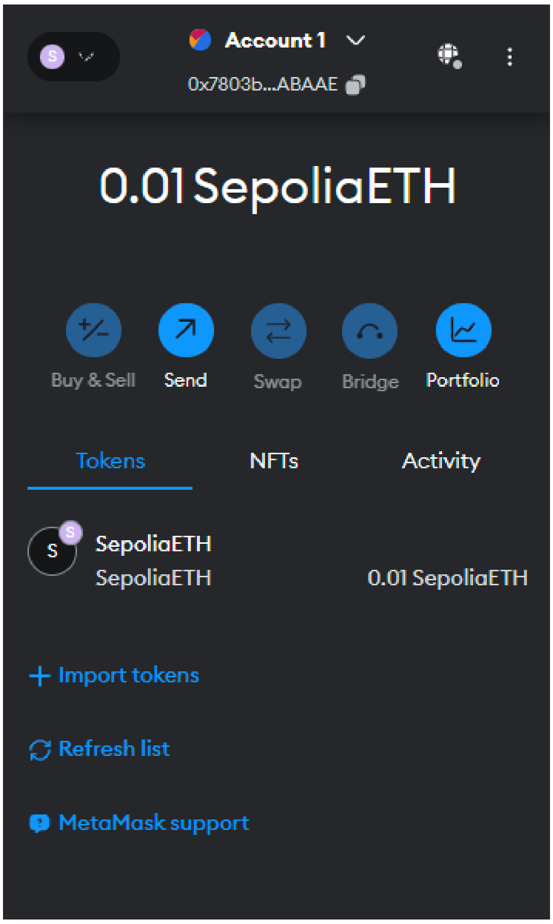

Figure 3.9: Metamask

3.4 Project Management and Software Analysis

For this study, the plan have been conducted carefully. Divided the project into several phases, each with clear goals and tasks. A timeline is used to track the progress and made sure to stay on track. I also identified potential risks and developed strategies to handle them.

In terms of software, detailed requirements were gathered from all stakeholders to ensure the software met all necessary specifications. The system architecture were designed to ensure it would be scalable, secure, and high-performing. A technology stack including Ethereum blockchain for transparency and security, Node.js for backend development, and React for the frontend interface.

Various tools have used to streamline the development process, such as Truffle for smart contract development and Ganache for testing. Testing was conducted to make sure the system met all functional and non-functional requirements. Finally, deployed the system on a local Ethereum blockchain for initial testing and planned for future deployment on a public network.

3.5 Summary

In this chapter, explains the planning and management of this project to ensure its success. Detailed the approach to project management, which included breaking the project into phases, setting clear goals, and assigning tasks based on each team member's strengths. Also discussed about how detailed requirements have gathered from all stakeholders to ensure met their needs. The system architecture was designed to be scalable, secure, and efficient. The technology choices included Ethereum blockchain for security and transparency, Node.js for backend development, and React for the frontend interface. Here various tools were used to help with development, such as Truffle for smart contract development and Ganache for testing. This system initially deployed on a local Ethereum blockchain for testing and planned for future deployment on a public network. This thorough approach helped me to address challenges effectively and deliver a high-quality solution for the pharmaceutical supply chain in Bangladesh.

CHAPTER 4
IMPLEMENTATION

4.1 Overview

This section, discusses about the construction of this blockchain system for the pharmaceutical supply chain. The combination of a frontend application with the Ethereum blockchain using Truffle is showed here. The frontend includes all the important files for the application, like the React application, assets and user interface components. The focuses on the key functions such as adding medicine, assigning roles and tracking medicines through the supply chain. The main smart contract, called SupplyChain.sol is explained, which defines roles like producers, distributors, retailers and raw material suppliers. This contract helps ensure transparency and traceability by recording all transactions on the blockchain. How the migration scripts deployed the smart contracts and configuration files to manage project settings and dependencies also described. With the help of Web3.js, the frontend and blockchain can talk to each other, allowing real-time updates in the application. The system flow begins with raw material suppliers and progresses through manufacturing, distribution, retailing and finally to the consumer, with each stage marked in the smart contract.

4.2 Prototype Design

In this system, the frontend application is integrated with Truffle, which is an Ethereum development environment.

1. client: It contains frontend application files like node_modules, public, and src directories. In node_modules React application is installed here and contains all the libraries needed for this project. The public directory contains public assets for the frontend, like html and image files. And src holds the React applications as well as the artifacts & component. artifacts have compiled smart contract artifacts that the frontend can use to interact with the contracts. And components hold some ui components.

    a) AddMed.js: Add medicine to the system.

    b) AssignRoles.js: Assign roles in the supply chain.
    c) Home.js: Is the home page of the application.
    d) Supply.js and Track.js: Track medicines throughout the system.

2. SupplyChain.sol: Main smart contract of the system, which contains the logic of the system. Roles in the supply chain, such as producers, distributors,

retailers, and suppliers of raw materials, are defined by this. Each role is responsible for progressing a medicine's stage, from ordering to selling. As every transaction is recorded on the blockchain, and is immutable and verifiable by all of the participants, the contract guarantees transparency and traceability. Some functions and logics of the smart contract are shown below:

3. migration: Contain script for deploying smart contracts to the blockchain.

4. package.json and package-lock.json: Define project dependencies and lock them to specific versions to ensure safe installation across environments.

5. truffle-config.js: Configuration file for Truffle settings, which is essential for how Truffle interacts with the Ethereum network. It includes configurations such as:
    a) Network settings for deploying contracts, which can include development environments and live networks.
    b) Compiler configurations, like the Solidity version.
    c) Mnemonic or private key information for account management.
    d) Advanced settings for gas price and gas limit for transactions.
    e) Settings for enabling optimizers in the Solidity compiler.

By handling smart contract development in the contract directory and storing the user interface in the client directory, this structure keeps issues separate. Configuration files are located at the root for project setup, and migrations are used to deploy contracts. A JS library, web3.js is used to allow interaction between the frontend and the Ethereum blockchain. It listens to smart contracts generated events, which help update the application in real time when specific actions are confirmed on the blockchain. It shows data in the application ui that is retrieved from the system, like the current status of medicines in the supply chain. The “SupplyChain.sol” smart contract's ABI (Application Binary Interface) and deployed address are used to create a contract instance in web3.js, enabling JavaScript to call the smart contract functions. Calls to smart contract functions that alter the blockchain state are made as transactions. These transactions are sent to the Ethereum network for mining using web3.js.

Depending on the role, this system has different users. For example, the smart contract can only be deployed by the owner. Raw material can be added only by the raw material supplier. A retailer can’t do this as the app is dynamic. The system flow begins with raw material suppliers, advancing through manufacturing, distribution, retailing, and finally to the consumer. Each stage is marked in the smart contract, and the React interface provides real-time updates.

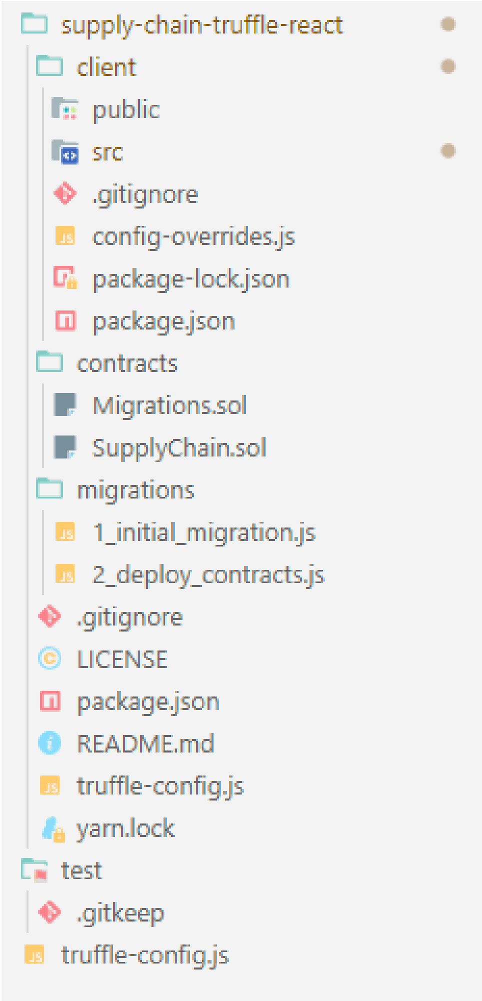

Figure 4.1: Project structure

Smart Contract: The SupplyChain.sol contract defines roles within the supply chain, such as raw material suppliers, manufacturers, distributors, and retailers. Each role is responsible for progressing a medicine's stage, from ordering to selling. The contract ensures transparency and traceability, as each transaction is recorded on the blockchain, immutable and verifiable by all participants. Some functions and logics of the smart contract are shown below.

```
//To store information about the medicine
struct medicine {
    uint256 id; //unique medicine id
    string name; //name of the medicine
    string description; //about medicine
    uint256 RMSid; //id of the Raw Material supplier for this particular medicine
    uint256 MANid; //id of the Manufacturer for this particular medicine
    uint256 DISid; //id of the distributor for this particular medicine
    uint256 RETid; //id of the retailer for this particular medicine
    STAGE stage; //current medicine stage
}

//To store all the medicines on the blockchain
mapping(uint256 => medicine) public MedicineStock;
```

Figure 4.2: Medicine information storing

```
//To show status to client applications
function showStage(uint256 _medicineID)
    public
    view
    returns (string memory)
{
    require(medicineCtr > 0);
    if (MedicineStock[_medicineID].stage == STAGE.Init)
        return "Medicine Ordered";
    else if (MedicineStock[_medicineID].stage == STAGE.RawMaterialSupply)
        return "Raw Material Supply Stage";
    else if (MedicineStock[_medicineID].stage == STAGE.Manufacture)
        return "Manufacturing Stage";
    else if (MedicineStock[_medicineID].stage == STAGE.Distribution)
        return "Distribution Stage";
    else if (MedicineStock[_medicineID].stage == STAGE.Retail)
        return "Retail Stage";
    else if (MedicineStock[_medicineID].stage == STAGE.sold)
        return "Medicine Sold";
}
```

Figure 4.3: Showing status to client application

```
//To add raw material suppliers. Only contract owner can add a new raw material supplier
function addRMS(
    address _address,
    string memory _name,
    string memory _place
) public onlyByOwner() {
    rmsCtr++;
    RMS[rmsCtr] = rawMaterialSupplier(_address, rmsCtr, _name, _place);
}

//To add manufacturer. Only contract owner can add a new manufacturer
function addManufacturer(
    address _address,
    string memory _name,
    string memory _place
) public onlyByOwner() {
    manCtr++;
    MAN[manCtr] = manufacturer(_address, manCtr, _name, _place);
}

//To add distributor. Only contract owner can add a new distributor
function addDistributor(
    address _address,
    string memory _name,
    string memory _place
) public onlyByOwner() {
    disCtr++;
    DIS[disCtr] = distributor(_address, disCtr, _name, _place);
}

//To add retailer. Only contract owner can add a new retailer
function addRetailer(
    address _address,
    string memory _name,
    string memory _place
) public onlyByOwner() {
    retCtr++;
    RET[retCtr] = retailer(_address, retCtr, _name, _place);
}
```

Figure 4.4: Adding stakeholders in the record

4.3 Model Evaluation

In this section, we will go through how the pharmaceutical supply chain of Bangladesh works.

1. System Initialization: The system starts with smart contract deployment on the Ethereum blockchain, where the truffle suit tool is used for deployment.

2. Participant Enrollment: All the participants, like manufacturers, retailers, distributors, and suppliers, register in the supply chain system with a unique address with which they can perform their specific role.

3. Product Registration: Enter medicine info to the supply chain system with their manufacture date, expiration date, ingredients, and batch number by

manufacturer. From here manufacture can track and trace the drug by this blockchain based supply chain system.

4. Verification and Distribution: Distributor receives the products from the manufacturer and validates them by their batch number on the supply chain system. After that distributors update the system with retailer and transportation info.
5. Retailer: Receive goods from distribution and update the system by confirmation of receiving and sales information of drugs when they are sold to the consumers.
6. Consumer: They can authenticate drug using the blockchain based system.

4.4 Summary

This part, I explains how to built the blockchain system for the pharmaceutical supply chain. The combination of frontend application with the Ethereum blockchain using Truffle is detailed and described key functions like adding medicine, assigning roles and tracking medicines to ensure everything is transparent and traceable. The main smart contract SupplyChain.sol described, which helps keep track of producers, distributors, retailers and suppliers which records all transactions on the blockchain, making the system secure and transparent. The use of migration scripts to deploy the smart contracts and configuration files to manage the project settings is also detailed. Finally, the system flow start from raw material suppliers to consumers, with each stage being tracked in the smart contract. This process ensures that the entire supply chain is transparent and secure.

CHAPTER 5
RESULT AND ANALYSIS

5.1 Overview

In this chapter, the results of the blockchain system for the pharmaceutical supply chain have been showed. The system is tested in different ways to see how well it works and looked at things like how fast transactions are, how many transactions it can handle at once and how secure the data is. User feedback from manufacturers to retailers was also collected to evaluate the systems effectiveness and their needs. The goal is to understand how effective the system is and what impact it can have on the pharmaceutical supply chain.

5.2 Experimental Result

The experimental phase involved rigorous testing of the blockchain system under various scenarios to assess its functionality, efficiency, and reliability. Key results include:

- Transaction Speed: The average time taken for transactions to be validated and recorded on the blockchain.
- System Throughput: The number of transactions processed per second.
- Data Integrity: Ensuring that data recorded on the blockchain remains tamper-proof and accurate.
- User Feedback: Surveys and interviews with stakeholders (e.g., manufacturers, distributors, retailers) to gather qualitative data on the system's usability and effectiveness.

The experimental results indicate that the blockchain system significantly improves transaction speed and data integrity compared to traditional methods. Users reported higher confidence in the authenticity and traceability of medicines.

Figure 5.1: System Home Page

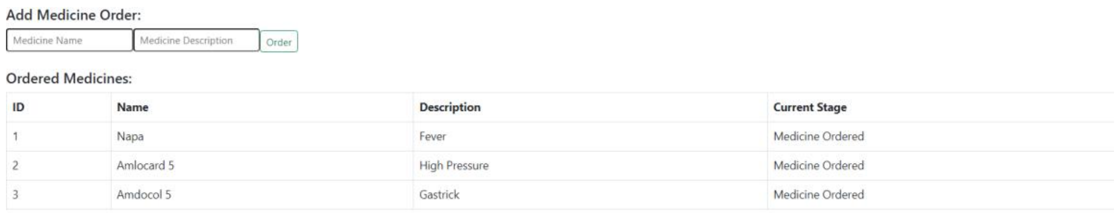

Figure 5.2: Add Medicine

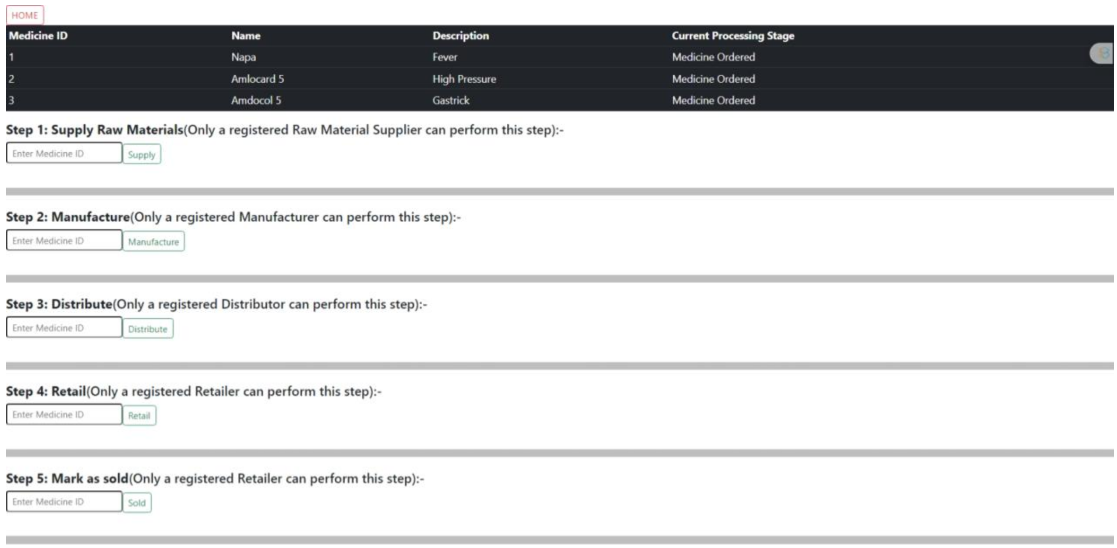

Figure 5.3: Supply Chain Control

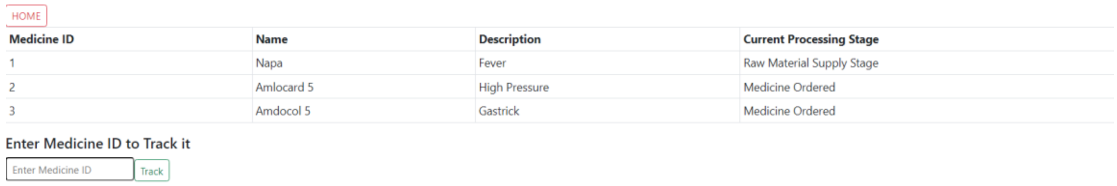

Figure 5.4: Track Medicine

5.3 Comparative Analysis

A comparative analysis was conducted to evaluate the performance of the blockchain-based system against existing supply chain management systems. Key comparison metrics include:

- Transparency: The blockchain system provides real-time visibility into the supply chain, allowing stakeholders to track the movement of medicines from production to delivery.

- Security: Blockchain's decentralized nature enhances security by reducing the risk of data tampering and fraud.

- Efficiency: The system streamlines processes, reducing the time and cost associated with tracking and verifying medicines.
- Scalability: The system's ability to handle increased transaction volumes without compromising performance.

The comparative analysis shows that the blockchain-based system outperforms traditional supply chain management systems in terms of transparency, security, and efficiency. However, scalability remains a challenge that requires further optimization.

5.4 Summary

In this chapter, showed the results of blockchain system for the pharmaceutical supply chain. Found that this system improves transaction speed and data security compared to traditional methods. Users said they felt more confident about the authenticity and traceability of medicines. A compared also held with existing supply chain systems. This blockchain system did better in terms of transparency, security, and efficiency. However scalability is still a challenge that needs more work. Overall this system shows promise for improving the pharmaceutical supply chain, but we need to continue working on making it scalable for larger use.

CHAPTER 6
IMPACT ON SOCIETY, ENVIRONMENT AND SUSTAINABILITY

6.1 Impact on Society

Implementation of blockchain technology in the pharmaceutical supply chain of Bangladesh has a huge impact on society as it provides a transparent, secure, and efficient platform. The society stands to benefit in the following ways:

1. Improving Drug Safety: Blockchain ensures drug safety and authenticity by providing a transparent distributed ledger.

2. Enhanced Trust: The immutable quality of blockchain technology keeps records safe of the entire supply chain, which builds trust among stakeholders and consumers.

3. Increased Medicine Accessibility: A better efficient supply chain leads to more consistency in availability of drugs to consumers.

Economic Enhancement: Maintaining a safe, reliable pharmaceutical supply chain can lead to increase the business in international markets.

6.2 Impact on Environment

The primary focus of the blockchain based pharmaceutical supply chain system is to provide a secure and transparent supply chain, but it also has a better impact on the environment. As a movement is held to technology from paper-based system, it will contribute to the paper reduction and minimize the physical documentation. It will protect the environment from deforestation and energy consumption that cause paper production. It will also lower the carbon footprint, which will be a great milestone.

6.3 Ethical Aspect

Integration of blockchain technology into the pharmaceutical supply chain system has some ethical aspects as well. Such as:

1. Only authorized users have access to sensitive data, which ensures that information is kept private and safe.

2. By providing an efficient and reliable supply chain, it ensures drug safety as well as evenly distributed distribution of medicine.

6.4 Sustainability Plan

Scalability: As we enter the world of digitization, the blockchain based system should be capable of handling vast amounts of data and transactions without compromising performance.

Upgradability: Technology evolves day by day. New features will be available in future. So, the system should be upgraded to match and implement new features that will arrive in future.

Engagement with community: Gathering feedback from the user is very essential in the age of new technology. It will help to develop a better system. So, a sustainability plan should include engagement with the community.

6.5 Summary

In this part, how using blockchain in the pharmaceutical supply chain can benefit society, the environment and sustainability have been explored. This blockchain-based system can make drugs safer, build trust among consumers and improve the availability of medicines. It also reduces the need for paper, helping the environment. We talked about the importance of privacy and security and the need for the system to grow and improve over time. We can make sure the system meets everyone's needs by engaging with the community. Overall, blockchain can bring many positive changes to the pharmaceutical supply chain in Bangladesh.

CHAPTER 7
CONCLUSION AND FUTURE WORK

7.1 Conclusions

To sum up, this study demonstrates how blockchain technology might improve Bangladesh's pharmaceutical supply chain. It clearly showed how blockchain has improved efficiency, transparency, and the decrease of counterfeit drugs, among other benefits, these have increased consumer trust. It also highlights the necessity of maintaining this technology's growth and adaptation in order to meet changing difficulties. This thesis stands out for its comparative study of different blockchain platforms. After reading this, one can acquire the in-depth knowledge required to choose a particular blockchain platform for Bangladesh's pharmaceutical supply chain. This article addresses the difficulties that will arise in integrating the blockchain solution. The thesis highlights the necessity of more research to investigate cutting-edge blockchain solutions and adjust to regulatory changes from Bangladesh's point of view. Overall, this study makes a substantial contribution to our knowledge of how blockchain technology might be applied to pharmaceutical supply chains, particularly in underdeveloped nations like Bangladesh.

7.2 Further Suggested Work

- Analyze how blockchain technology and artificial intelligence may be combined to improve medicine distribution prediction.
- Creating a blockchain platform with a focus on supply chain management.
- Explore how tracking a product's lifecycle impact using blockchain can help the pharmaceutical industry's sustainability objectives.
- Think about how tracking a product's lifecycle impact using blockchain can help the pharmaceutical industry's sustainability objectives.
- Evaluate the long-term environmental effects of blockchain technology in the pharmaceutical supply chain.
- Investigate how stakeholders and customers are accepting of blockchain technology.

7.3 Limitations

1. The paper lacks detailed action plans for developing and testing decentralized applications (dApps), focusing more on theoretical discussions.

2. Ethical and regulatory challenges are noted but not explored in depth, particularly regarding potential barriers and dilemmas during implementation.

3. Scalability and upgradeability concerns are highlighted, but the paper does not provide a detailed analysis of how these challenges will be handled.

4. Sustainability planning includes gathering user feedback, but the paper lacks specific strategies for engaging with communities and systematically integrating feedback.

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APPENDIX

Throughout this study, I have faced a lot of challenges. An appropriate methodology selection was the initial step. The largest challenge I had, though, was that, as a student with a background in computer science, I didn't have a thorough knowledge of the system's research. I have gained some knowledge by reading many papers on this subject. Ethics in this research was paramount i.e. ensuring a safe pharmaceutical supply chain. Future research could include its use on a larger scale and the use of Ai.

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