<u>Indian Institute of Technology Roorkee</u>

MIN-400B B.Tech. PROJECT

Spring 2021

<u>Aim</u>: **Decentralized Supply Chain Using Blockchain**

(Mechanical and Industrial Engineering)

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PREAMBLE

ABSTRACT

In the traditional supply chain, the information about the product is not fully visible to others, which leads to inaccurate reporting and a lack of interoperability. Since the blockchain is an immutable, transparent, and secure decentralised system, it is considered a cutting-edge and innovative solution for traditional supply chain industries. It can benefit the supply chain as follows:

- Tracking the products in the entire chain
- Sharing the whole chain information between supply chain actors

A study by various reports indicates that counterfeit products entering the mainstream supply are among the significant issues faced by the pharmaceutical industries. Various challenges faced by the stakeholders can be resolved by using blockchain as a ledger. By design, blockchain is (i) robust, (ii) improves transparency, (iii) immutable, (iv) authentic, (v) reliable and (vi) secure. By sharing a product's information over an immutable supply chain framework, we can enable the end consumer to self-verify the product's authenticity.

SOFTWARE

The complete code of this project is stored in the Git repository located at:
https://github.com/BLOCK-PHARMA/BlockPharma.git.

To interact with our supply chain model, the following is the website link:
https://blockpharma.ml/.

ACKNOWLEDGMENTS

We want to convey our sincere gratitude to our faculty supervisor Dr Akshay Dwivedi for his guidance and support during the project. Even though the Covid-19 pandemic was wreaking havoc in the country, Dr Dwivedi ensured a smooth progress curve. Through his insightful and challenging questions, Dr Dwivedi prompted us to deepen our understanding of blockchain and its use cases and offer invaluable advice on managing the project during our regular meetings. Lastly, we would like to thank our Mechanical and Industrial Engineering Department batchmates and professors who gave us first-hand inputs and vital industry viewpoints and constructive feedback on the project.

CONTENTS

CHAPTER 1: Introduction

1.1 Motivation

In the current era dominated by information technology, the traditional supply chain model possesses various bottlenecks and flaws. Firstly, the information flow, logistics, and many participants in the network cause various delays and mismanagement. Secondly, the centralised data management system faces the problems of data vulnerability to illegal tampering and difficult accountability tracing. Finally, for consumers and regulators, when they want to know the production history of the products they buy, it may take one to two weeks or more to trace back the information under the traditional supply chain supervision system.

To elaborate on how the pharmaceutical industry has been affected due to the factors mentioned above. According to the WHO, tens of thousands of deaths occur in developing countries due to fake drugs. Counterfeiting is not the main reason itself; instead, these counterfeit drugs produce different side effects on human health. It is challenging to detect counterfeits because they pass through other complex distributed networks, thus presenting opportunities to the counterfeits to enter the supply chain. Considering the concern for public health, many organisations emphasise drug traceability using the latest technology such as Blockchain.

1.2 Problem Statement

Develop an end to end network for a pharmaceutical Supply chain with immutability and improved accountability using blockchain technology.

1.3 Proposed Solution

This project proposes a new tracking system and secure transfer of product through Blockchain's supply chain management system. Also, we use the distributed public permission ledger and with the Ethereum Blockchain. We decreased the errors, avoiding product delays, eliminating fraud activities. The Smart Contracts will transfer the product ownership from one player to another player, and each player checks the product to eliminate the errors and fraud activities.

1.4 Objectives

The objectives of the project are as follows:

- Build an ethereum based blockchain by studying existing pharmaceutical supply chain models.
- Include different roles like manufacturer, wholesaler and retailer in the blockchain using smart contracts.
- Host this blockchain network on Ropsten Network and Ethereum Mainnet for scalability and transparency.
- Test this network for concurrent operations, latency, throughput, etc.

1.5 Technologies Used

We have been using numerous online platforms to communicate and ease our primary project development. Others may also include an online project management tool introduced by the Project instructors and supervisors.

1.5.1 Tools Used

- Nodejs
- Truffle
- Solidity
- Ethereum Network
- Metamask
- Ganache
- Web3JS
- Github
- Browser Stack
- WebLoader

1.5.2 Programming Languages used

- Javascript (Backend)
- HTML/CSS (Frontend)
- Solidity (Smart Contracts)
- Node.js (Backend)

1.6 Report Structure

The following sections constitute the report:

1.6.1 Background

An overview of current literature covering supply chain traceability and blockchain. First, some background on traceability. Second a background on blockchain, and lastly, a brief discussion on the various types of supply chain models.

1.6.2 Specification

This section briefly discusses the business context of the traceability system and desired requirements of the proposed approach.

1.6.3 Design

It contains a detailed design of the proposed system as per the requirements discussed. Specifically, the various blockchain platforms are discussed along with the choice of supply chain network model.

1.6.4 Implementation

This section describes how the proposed design is actualised, and it contains descriptions of the various tools and data models.

1.6.5 Security

It contains a detailed description of the security features used in the proposed system to prevent it from any form of cyberattacks,

1.6.6 Testing

This section discusses the testing strategy used and discusses the results achieved during performance testing.

1.6.7 Discussion

The section contains an overview of the work, how the product can be incorporated into real-world scenarios and further scope of improvement.

1.6.8 Conclusion

The final section contains the conclusion of the developed model.

CHAPTER 2: BACKGROUND

2.1 Traceability

2.1.1 What is traceability?

Many research papers tackle the subject of traceability, especially in the food industry. It is necessary to understand what exactly we are tracking.

There are two types of traceability:

1. **Product**: It is related to the materials, origins, processing history, and distribution.
2. **Data**: It is related to the calculations and data generated throughout the quality loop.

ISO standard defines product traceability as “the tracking of consumer products concerning the origin of materials and parts; the processing history; the distribution and location of the product or service after delivery”. The European Union describes traceability similarly as “an ability to track any food, feed, food-producing animal or substance that will be used for consumption, through all stages of production, processing and distribution”.

Overall, traceability may be loosely defined here as tracking a physical item through certain transformations or a chain of custody.

2.1.2 Example use case

Let’s take an example of traceability in the food industry. To protect the name ‘Parmigiano Reggiano’ against imitations, a consortium of Italian providers implemented a traceability system to certify authentic cheese. A cow’s milk is traced to a dairy where it is made into cheese; the cheese is then tracked throughout its lifespan during ageing and distribution to retailers.

Information is recorded at multiple stages in the supply chain; for example, at the dairy, attributes such as cooking temperature and the cow code are recorded. After this, an RFID chip is attached to uniquely identify that ’batch’ (a wheel) of cheese. After production, the cheese is aged in a warehouse, where attributes such as temperature and humidity are tracked. Before being sent to market, the cheese is cut into smaller portions with an alphanumeric identification number printed on the packaging.

This all serves to give complete traceability of the cheese from cow to table, meaning customers can be confident the cheese they are eating is authentic Parmigiano Reggiano.

2.1.3 Benefits of traceability in the supply chain

Following are some of the benefits of traceability in the supply chain:

- Improves the integrity of the supply chain
- Trace products back to their origin
- Track products from source to consumer
- Reducing the risk of mislabeling
- Perform more effective audits by having complete information at hand

2.1.4 Issues with existing supply chain traceability systems

These are some of the significant issues with the existing supply chain traceability systems:

- Data Tampering
- Single point of failure with a centralised storage
- Dubious traceability information
- Distrust of authorities on data authenticity
- Lack of provenance

2.2 Blockchain

2.2.1 What is Blockchain

Blockchain at first glimpse may seem complicated, but its underlying concept is pretty intuitive. Blockchain is based on distributed ledger technology and is used to record and transmit transparent, controllable, secure, and fault-tolerant data. Blockchain helps organisations in becoming decentralised, safe, transparent, efficient, and democratic. Blockchains are also referred to as database management systems, but there is a critical difference between how data is stored. While traditional DBMS stores the data in tables, blockchain stores it in a series of data chunks or blocks. Blockchains are generally segregated into three categories, i.e., public blockchain, private blockchain, and consortium blockchain.

This report focuses on the pharmaceutical supply chain. Besides the pharmaceutical industry, many other sectors have exploited blockchains like supply chain management, networking and internet of things, forecasting, banking and payments, insurance, forecasting, private transportation, carpooling, voting, real estate, government, charity, health, energy management, forecasting, online music, online data storage, and retail.

2.2.2 How does Blockchain works

The main aim of a blockchain network is to store data in a decentralised and distributed manner. Each block consists of records of previous transactions that are encrypted and hashed by keccak256. The application is based on a user-centric framework that uses Ethereum blockchain and smart contracts as a medium to communicate. In the proposed system, the user sends a transaction proposal through the web network to call backend services like drug registration and ownership transfer provided by the blockchain network. The blockchain network is equipped with Create, Read, and Update operations that regulate the data transfer between the connected nodes.

The node stores data of transactions and contains a smart contract that can endorse the transaction or write a blockchain transaction block. The blockchain consensus algorithm aims to ensure that only a unique history of transactions exists, and it does not contain any contradictory or invalid transactions. Blockchain technology records the decentralised, transparent, and immutable transaction histories and logs of all the network's actions and events. To maintain every transaction's consistency, different consensus and cryptographic protocols have been employed, e.g., digital signatures and hashing. A node in a network sustains the replica of a blockchain, also processes the transaction simultaneously, updating the blockchain. The node in a blockchain comprises blocks, policies, smart contracts, and state databases. The state database represents and stores the state of the transactions at a given point in time.

A smart contract provides functionality to the blockchain as a program that can access blockchain blocks and execute transactions. It is a program that is stored in a decentralised database. Smart contracts consist of business logic, constraints, and validations to transactions. They are analogous to database triggers and serve as an agreement between parties. It contains functions that act as an intermediary between users and the ledger. Users can query their information by performing a transaction to the smart contract. The proposed application, based on smart contracts and blockchain, processes the transaction, queries, and updates the state of blockchain by affixing the transaction in blocks and providing the updated result to the application as a response.

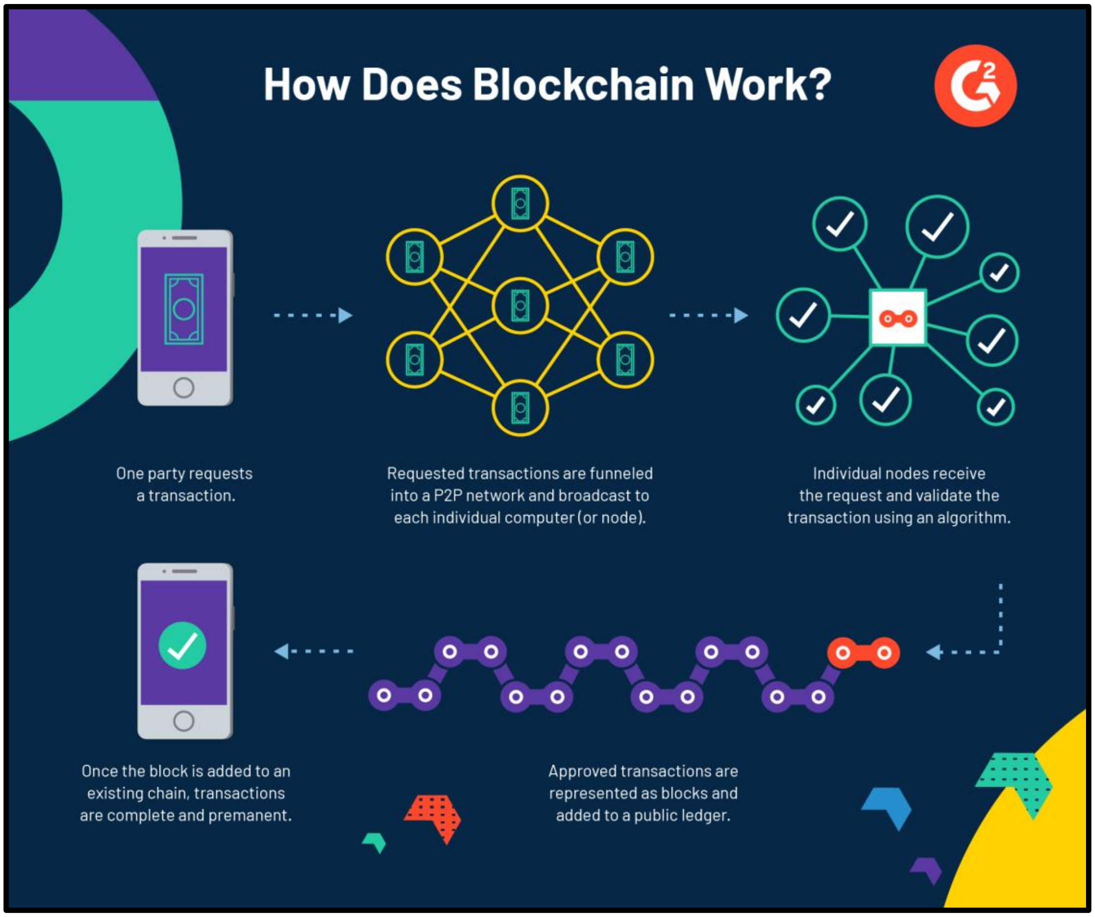


Fig 2.1:Blockchain at Work[46]

2.2.3 Benefits of a blockchain-based system for traceability

After various discussions on traceability, it is evident that interoperability between participants is one of the biggest hurdles in improving supply chain traceability.

Blockchain systems are designed to be distributed, with entities sharing transaction information through the ledger. As a result, blockchain could be a suitable technology framework for implementing a traceability system because blockchain platforms have many technical requirements for a traceability system.

2.2.4 Evaluating if blockchain is a good fit for an organisation

After the above discussion, it may seem that blockchain technology could be applied in a traceability context, but it is also essential to look at things from a higher level. Since the supply chains can vary across various verticals, it is necessary to evaluate whether they should be used at an organisational level or not. Multiple frameworks could help identify the same, for example, Jansson and Peterson's paper.

2.2.5 Levels of Blockchain adoption

Blockchain could be used at multiple levels depending on the type of usage. For example:

- In a single organisation, it could be used to add and replace internal databases.
- Over multiple organisations, it could simplify complex transaction interactions such as tracking batches of commodities through steps in a supply chain.

2.3 Supply Chain

Since we will apply blockchain in the supply chain, it is essential first to understand what the supply chain is. A commodity moves from the manufacturing plant to the market with the supply chain's help through a sequence of events. The supply chain contains people, technology, transportation modes, and equipment. Supply chains are present in both the manufacturing and service sectors.

Fundamentally all supply chains focus on either efficiency or responsiveness. But considering other factors also, the supply chain can be divided into six types:-

1. **Continuous flow model**:- This model provides stability in situations with high demand. It can also benefit the manufacturers that repeatedly produce the same goods with minimal fluctuation. It is one of the traditional supply chain ideals for commodity manufacturing.
2. **Fast Chain**:- The fast chain model is ideal for manufacturers that manufacture products that are trendy with short life cycles. A business that must frequently change their products, which needs to get them out fast before the trend ends, works well. It is a flexible model.
3. **Efficient Chain Model**:- The efficient chain model is best for businesses in very competitive markets and where the end to end efficiency is the premium goal.
4. **Custom Configured Model**:- The custom configured models focus on providing custom configurations, especially during assembly and production. It combines the agile model and the continuous flow model, a hybrid of sorts.
5. **Agile Model**: It is ideal for businesses that deal with special order items and is a supply chain management method. It mainly focuses on the supply chain's ability to ramp up in some cases and be stable in low movement.
6. **Flexible Model**:- To meet the business's high demand peaks and manage the long periods of the low volume movement, this model is used.

The below-attached image discusses how blockchain affects supply chain roles.

	Relation and impact to the Supply Chain roles
Scalability	Scalability is improved since the suppliers are participating in a general system of the supply chain (not different ones depending on the different companies as in traditional supply chain architecture). The Peer-to-Peer nature of blockchains is by design more robust and scalable given the fact that the there is no single point of interaction (as compared to centralized solutions). Distributors scalability is improved since in a common ledger all their customers (wholesalers, retailers) can be effortlessly accessed (no need for different supply chains for different customers). Blockchain scalability improves consumers experience since they are more aware of the supply chain size and functionalities through transaction tag information and their trust towards the system increases.
Performance	Blockchain performance enhances this step since transaction submission and verification high speed (comparing to traditional bank methods) provides quick and trustful liquidity of payments. Recent blockchain implementations are being designed as to facilitate a high throughput of transactions per second.
Consensus	Blockchain consensus offers trust to the whole supply chain system. Country origin, quality and other details are recorded as tags on the ledger, adding value to the final product. It benefits the Distributors stage since the raw materials are validated and the manufacturer signature is checked, which all together add value to the final product. It also helps vitally this stage since the retailers are assured that the final product which is about to be sold to the end users has all the exact natural resources and passed through all the manufacturers, distributors and wholesalers that the ledger confirms. Consumers are confident that the product quality and general characteristics are the ones that the blockchain ledger confirms they are; value is added to the product.
Privacy	Although blockchains are considered public ledger, privacy can be engineered in a way to facilitate access control to who is going to have access to the information contained in the blocks. Blockchain provides privacy in the sense that private transactions are not visible (but are legitimately verified) by parties that transaction issuers might not want to display. It also helps keep identity of users private when it is needed, but still verifying values that are essential for the consistency of a products journey, such as raw material quality, distributor geolocation and others.
Location	Supply chain dependency on location becomes flexible. Raw materials are transferred around the world while transactions are not dependent on country regulations and laws; with rapid submission and validation rates. Manufacturers are cooperating with different supplier and distribution companies around the world while transactions are country regulation and law independent with rapid submission and validation rates. Distributors are cooperating with different wholesale and retail companies around the world while transactions do not depend on country regulations and laws and are accomplished with rapid submission and validation rates. Additional measures and methods for proof-of-location mechanisms are being considered these days as a way to prove the location through its registration to a blockchain that cannot be disputed.
Cost	Blockchain transaction costs can be significantly reduced comparing to traditional payments with banks. In contrast with banks, crypto-payment fees are negligible, especially when transferring funds between countries with different regulations and economy laws. Suppliers are paid faster for the natural resources that the sell to manufacturers, while the later are charged subtly on their purchase. Distributors are compensated quicker for their offered products, while the wholesalers or retailers benefit from the low fees. The final product overall value is increased while at the same time its price is substantially decreased which both leave the consumer happier than in the traditional supply chain system in terms of quality and price.

Fig 2.2: BlockChain Elements that affect Supply Chain roles

CHAPTER 3: SPECIFICATION

3.1 Business Context

Tracing any product back to its origin requires a lot of time in the traditional supply chains. The data concerning this traceback could easily be modified, or any counterfeit product could be added between the supply chain indistinguishable from the original product. These problems could cause a massive loss to the participants involved in the supply chain. Therefore it is needed to solve these problems, that too, without any huge tradeoff. Our system solves these above-discussed problems by utilising the concepts of blockchain traceability and decentralisation. Our blockchain-based supply chain is immutable, and therefore any counterfeit product at any stage of the supply chain can be easily identified. The underlying principle of blockchain utilises Merkel Tree, which can easily track the product back to its roots in the supply chain. This modern formulation of our supply chain possesses a considerable benefit for its stakeholders and users. We have shown the effectiveness of our supply chain for the pharmaceutical industry, but it can easily be adjusted to any other use case.

There are some preconditions for the adoption of these blockchain-based supply chains4. They are mentioned below:-

Typically, multiple organisations take part in a supply chain system. It is reasonable to assume different organisations have different technology stacks, perhaps using another cloud infrastructure provider. Ideally, the design should run on multiple hardware platforms on common or easily accessible platforms such as GCP or AWS. It is not feasible for all organisations in the supply chain to immediately switch over to an entirely new supply chain. Adopting the system should be possible in an incremental manner, i.e. the system must present an interface enabling it to integrate with existing systems. The specific implementation of business logic within a supply chain will vary widely between use cases and industries. Developers within an organisation should find it straightforward to generalise the software implementation given in this paper when creating a system tailored to their use case.

3.2 Requirements for adoption

Companies need a technical framework for creating blockchain supply chain systems and a process to follow for integrating blockchain into their supply chain. Implementing a sufficiently

complex supply chain model could serve as a proof of concept and a valuable point of reference for developers creating similar systems within their organisation.
The concept of a Traceable Unit (TRU) will factor into the data model, but the physical realisation of this, for example, an RFID chip, is out of the scope of a software project. Here, we assumed each pharmaceutical could be allocated a unique identifier, thinking it would be attached to the drug in the real world, for example, via a label with a barcode. The majority of my technical requirements have been taken from a collection of sources from literature. From there, we get the high-level user requirements from a successful traceability system and extrapolate those to the features of a system implementing traceability capabilities. Requirements for successful implementation of blockchain technology in the supply chain are as follows:

Req 1) Record data every time a TRU is sold or converted into another TRU.
Req 2) The record of traceability information must be queryable, allowing users to find the whole history.
Req 3) The system must allow credentials for participation in the network to be issued and revoked.
Req 4) The system must support expressive access control based on identity so operations on and views of data in the network can be restricted.
Req 5) The system must include some consensus mechanism to ensure all participants agree on the ledger's state.
Req 6) The system should run on multiple hardware platforms, ideally on common or easily accessible platforms such as GCP or AWS.
Req 7) Adopting the system should be possible in an incremental manner, i.e., the system must present an interface enabling it to integrate with existing systems.
Req 8) Developers within an organisation should find it straightforward to generalise the software implementation in this paper when creating a system tailored to their use case.
Req 9) The system must have low running costs and the potential for high transaction throughput.
Req 10) The system must have the ability to update software and business logic while the network is running without losing the traceability history of assets.
Req 11) The system must have the ability to add participants to the network while it is running.
Req 12) The system should have longevity and store the traceability history of old or long-lived items.

CHAPTER 4: DESIGN

4.1 Blockchain Platform

Blockchain at first glimpse may seem complicated, but its underlying concept is pretty intuitive. Blockchain is based on distributed ledger technology and is used to record and transmit transparent, controllable, secure, and fault-tolerant data. Blockchain helps organisations in becoming decentralised, safe, transparent, efficient, and democratic. Blockchains are also referred to as database management systems, but there is a critical difference between how data is stored. While traditional DBMS stores the data in tables, blockchain stores it in a series of data chunks or blocks. Blockchains are generally segregated into three categories, i.e., public blockchain, private blockchain, and consortium blockchain. This report focuses on the pharmaceutical supply chain. Besides the pharmaceutical industry, many other sectors have exploited blockchains like supply chain management, networking and internet of things, forecasting, banking and payments, insurance, forecasting, private transportation, carpooling, voting, real estate, government, charity, health, energy management, forecasting, online music, online data storage, and retail.

Since we will apply blockchain in the supply chain, it is essential first to understand what the supply chain is. A commodity moves from the manufacturing plant to the market with the supply chain's help through a sequence of events. The supply chain contains people, technology, transportation modes, and equipment. Supply chains are present in both the manufacturing and service sectors.

4.1.1 Pre Existing Platform

An essential part of the design phase of this project is choosing the software platform on which to build. As can be observed from the literature review, there are many options to choose from - Ethereum, Hyperledger, Multichain, or use blockchain from scratch. The use of an existing software platform was better suited for the overall objectives of the project. This project aims to provide an alternative supply chain framework, so choosing an existing and well-known platform and the customised implementation was critical in achieving it and ensuring that the implementation will make various use cases without any problems. The use of an existing platform also enables business acceptance because it is highly trusted.

4.1.2 Public vs Private

Public blockchains are designed for high transactions, but private blockchains tend to be less costly due to their simple compliance process. With a simple consensus, there is a chance the evil characters will ruin the book's history. In a business alliance, where companies collaborate on the same supply chain, this can be a problem because participants are limited. The consortium will have to verify the participants' ownership before allowing them to join. The public blockchain provides for transparent and accurate end-to-end tracking. So, organisations can create digital content on their own and create a consistent track record of everything done, making it easier to track assets from production to delivery or use by the end-user. One of the great benefits of social blockchain is that there is no need to trust each other. Everything is recorded, is public, and cannot be changed. Everyone is encouraged to do the right thing in improving the network—no need for mediators.

4.1.3 Feature Set

It is essential to determine which platforms provide the necessary feature set described in the requirements. What follows is a summary of the conditions we have decided to be most important to platform selection for each platform. Of course, it may be possible to bolt on features where they do not already exist for a platform, but unless there are other advantages, the platform that fulfils the most requirements out-of-the-box will be selected. Below is an assessment of the feature sets of the three most popular private blockchains - Ethereum, Hyperledger, and Corda.

Requirement	**Ethereum**	**Hyperledger**	**Corda**
Decentralised	Yes	No	Yes
Smart contracts	Yes	Yes	No
Access control	Yes	Yes	Yes
Consensus	Yes	Yes	Yes

4.1.4 Decision

Our solution uses the Ethereum blockchain and operates in public permission mode. The currency of Ethereum, i.e., Ether or ETH, is used as the payment system. Furthermore, the data is stored on-chain. Finally, our solution has programmable modules, which are smart contracts. Thus, proving to be an optimum choice amongst the others.

4.2 Ethereum

Subsequently, having selected Ethereum follows an exploration of the architectural concepts, showing how these relate to the requirements.

4.2.1 Background

Ethereum is a smart contract-based functionality, which is decentralised and open source in nature. The cryptocurrency native to the platform is Ether or ETH. It is second to Bitcoin only in market capitalisation. Ethereum is the most actively used blockchain.

Developer Vitalik Buterin launched Ethereum in 2013, and investors heavily funded development in 2014, and the network went into effect on July 30, 2015, with the initial release of 72 million coins. Ethereum Virtual (EVM) machine can run decentralised apps or DAPPs.

Ether (ETH) is a cryptocurrency produced by the Ethereum protocol as a reward for miners in a proof-of-work consensus function to add blocks to the blockchain. It is the only money received in the payment of transaction fees, which also goes to miners. The blockchain rewards and transaction fees provide an incentive for miners to keep the blockchain growing (e.g., processing new transactions).

4.2.2 Identity

The accounts identify participants in the blockchain. Two types of accounts exist in Ethereum: user accounts (also known as external accounts) and contracts. Both types have an ETH balance, send ETH to any account, call any public contract function, and are identified in the blockchain and the province by their address. User accounts are the only type that can initiate transactions. For a valid transaction, it must be signed using the secret key of the account, a 64-character hexadecimal series that should only be known to the account holder. Contracts are the only type of account with the code (a set of functions and declaratory declarations) and contract data storage (flexible prices at any time). Contracts are non-active entities and can only do anything if another account is calling one of its functions.

Ethereum addresses are built with the prefix "0x", a standard hexadecimal identifier, connected to the 20 right bytes of the Keccak-256 hash, the public key of the ECDSA (used curve called secp256k1). In hexadecimal, 2 digits represent a byte, mean addresses containing 40 hexadecimal digits, e.g. 0xb794f5ea0ba39494ce839613fffba74279579268. Contract addresses are in the same format.

4.2.3 Consensus

When it comes to blockchains like Ethereum, that is, still distributed data, network nodes must agree on the system's current state. It is obtained through consensus methods.

- **Proof of Work**: Proof of Work is provided by miners, who compete to build new blocks full of completed transactions. The winner shares a new block with the rest of the network and receives the newly created ETH as a reward. The network is kept secure by saying that you will need 51% of the network's computing power to decrypt the network.
- **Proof of stake**: Proof of stake was provided by certificates that have placed ETH to participate in the network. The authenticator is randomly selected to create new blocks, share them with the network and earn rewards. The plan to ensure that the blockchain is kept secure is that you will need 51% of the total ETH to defraud the chain. And that your stake has been confiscated because of illegal behaviour.

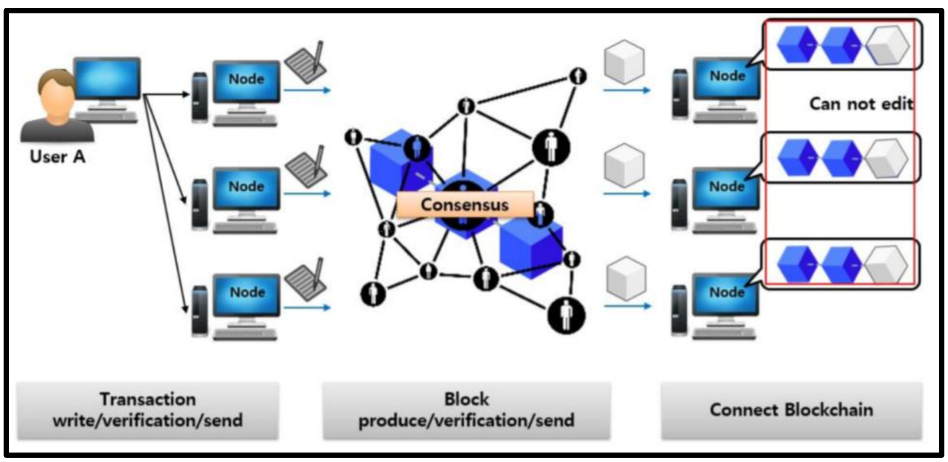


Fig 4.1 Consensus Algorithm[48]

4.2.4 Access Control and Privacy

Access control - meaning "who is allowed to do this" - is essential in the world of smart contracts. Controlling access to your contract can govern who can mix tokens, vote on proposals, file transfers, and much more. The most common and essential access control method is ownership: an account owns the agreement and can perform administrative tasks. This approach makes perfect sense in single-user agreements.

The central technology used for privacy is called 'zero-knowledge proofs.' This technology allows for privacy by mathematically preventing certain information (such as amount, sender, recipient, etc.) from being revealed to the public. At the same time, the protocol can still guarantee the transaction executes correctly.

4.2.5 Queries

Web3.js can be used to effectively inquire and listen to contract events in the Ethereum blockchain, enabling the specification of actions that occur when a specific criterion is met.

4.2.6 Integration

Web3j is a lightweight, highly modular, reactive, type-safe Java and Android library for working with Smart Contracts and integrating with Ethereum blockchains. It allows us to work with Ethereum blockchains without the additional overhead of writing our integration code for the platform. This API provides a standardised interface for client applications to interface with the network.

4.3 Ethereum Test Networks

Ethereum test networks make the development process easy and offer developers and organisations an easy solution to test their product on networks that are not transacting real value but simulating the same service.

The three main public test networks are:

- Ropsten
- RinkeBy
- Kovan

All ethers in these networks are worthless since these are only for testing purposes. We can use our decentralised application connected to either one of those networks without losing any real money.

4.3.1 Ropsten Network

Ropsten is the TestNet that most resembles the main network because it uses the same “Proof of work” consensus algorithm, i.e., nodes are responsible for maintaining the network. They use computing resources to generate blocks and keep the blockchain up to date. Blocks are inducted at an average of 30 seconds, and both Geth and Parity support this network.

4.3.2 Rinkeby Network

On this network, the consensus algorithm differs slightly from the latter because it uses the consensus algorithm called "Proof of Authority." It means that one needs to prove their existence to retrieve the ethers from a faucet. All the ethers are already mined and distributed only on-demand. Proving one's existence is as easy as posting something on social media and using a link to prove you're indeed the real deal. Blocks in the chain are generated at intervals of 15 seconds, and Geth only supports this network.

4.3.3 Kovan Network

Like the Rinkeby network, the consensus algorithm used is “Proof of Authority.” All the ethers are already mined and gained via a faucet. The advantage of using a POA consensus algorithm is immunity against phishing and spam attacks. Blocks on the Kovan network are added to the blockchain at intervals of 4s on average, and this network is only supported by Parity.

4.3.4 Decision

We chose Ropsten TestNet because of its similarity with the Ethereum Mainnet and the easy availability of Ropsten TestNet Ethers.

4.4 Supply Chain Model

No perfect model can represent all supply chains due to its broad spectrum. However, it is still critical to have a model builder that declares the scope of the supply chain model, reflecting the critical real-world situation. After analysing and synthesising the supply chain model design, the figure illustrates the proposed model of the supply chain in this project, which defines the structure vertically and horizontally. The horizontal layers refer to the amounts of different roles with different functions through the supply chain. The length of horizontal layers depends on the tiers of the supply chain, which may belong because of large tiers, or short due to fewer tiers. The vertical layers refer to the number of different entities within each horizontal layer. In practice, one specific model structure depends on the vertical and horizontal dimensions of the supply chain.

This project contains two basic interaction flows travelling across the entire supply chain model: physical flow and information flow.

- **Physical Flow**: Compared to other marketplaces, the supply chain has a single direction of physical flow, from origin to endpoint, without repeatedly trading back-and-forth between the participants and transacting with other competitors vertically.
- **Information Flow**: The information flow is usually a backward flow in contrast to physical flow. It is directly linked to the material flow: used to produce the product or service (e.g., order information, shipping information, quantity information, etc.)

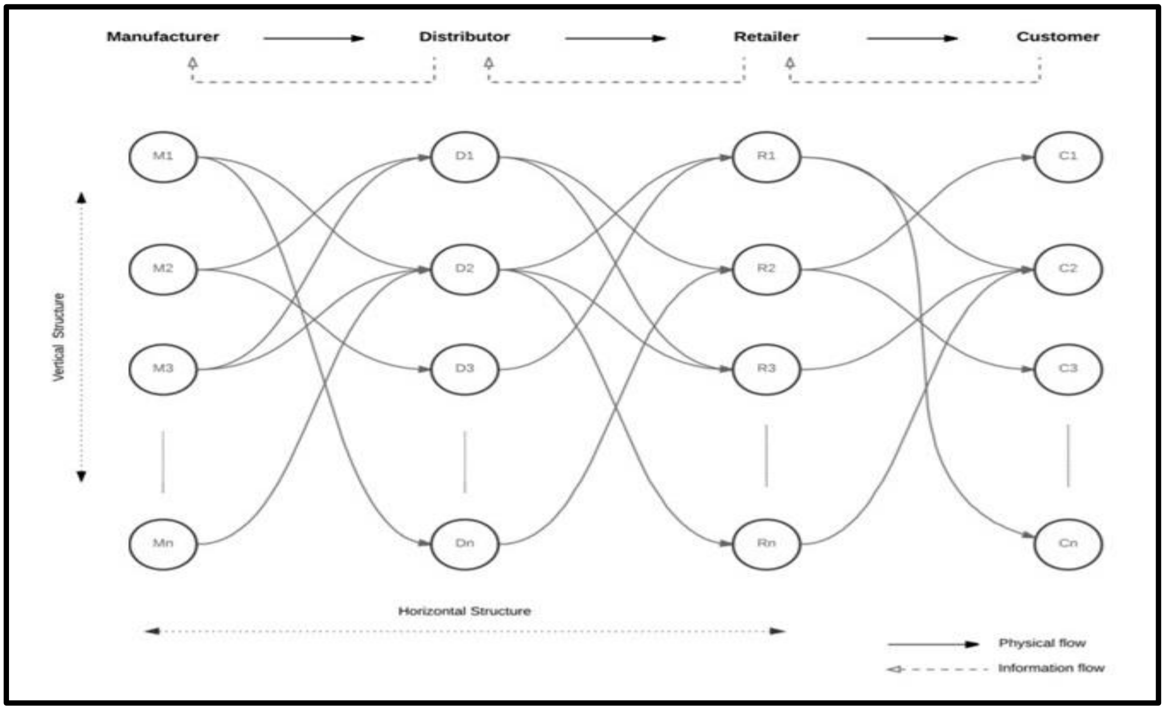


Fig 4.2: Supply Chain Network Model[49]

CHAPTER 5: IMPLEMENTATION

5.1 Concept of MVP

In this project, a mix of agile and incremental software design and development methods has been used because of the unfamiliarity with the Ethereum platform. A Minimum Viable Product (MVP) was created that included the supply chain, network model. For a Minimum Viable Product, the supply chain network for the first three participants in the chain - “Manufacturer,” “Wholesaler,” and “Retailer” - was implemented. The MVP should implement basic data models for these participants, including the transactions between the two, and should run on the Ethereum blockchain.

5.1.1 Network Model

The prototype model was to be built with three stakeholders as follows:

- **Manufacturer**: Able to register his drugs. Able to transfer ownership to the wholesaler.
- **Wholesaler**: Create consignment of the drugs as per order. Transfer ownership of the consignment to the Dealer.
- **Dealer**: Receives the consignment and sells medicine to the customer. The Dealer would be able to track back each drug to its manufacturer.

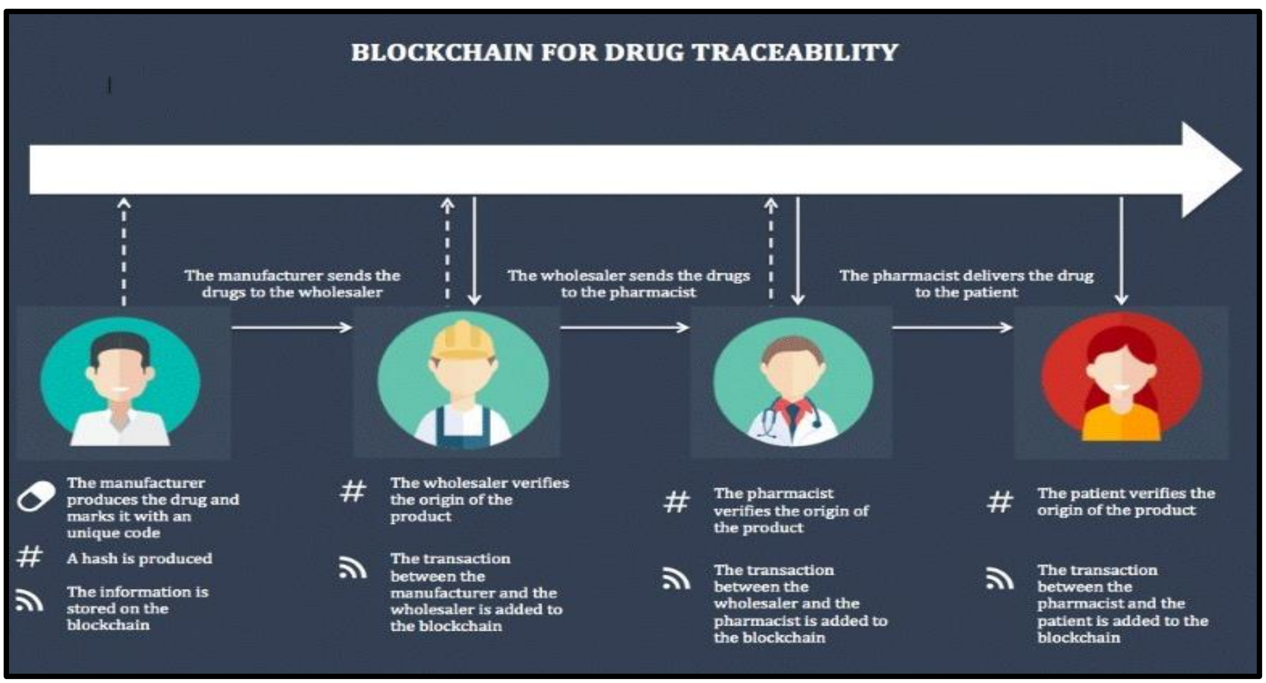


Fig 5.1: Smart Contract Roles[50]

5.1.2 Data Model

In the model, the contract layer was made of three contracts:

- **Migrations** are files that help deploy new changes in the contract to the ethereum blockchain. And this migration contract helps keep track of scripts of which migrations have been executed already.
- **ProductManagement** consists of separate functions for registering drugs and consignments/orders, even though both operations' requirements are very similar. Drug registration: create a mapping given the specifications of the drug itself (type, serial number, and creation date), the manufacturer that made it(owner id). Order registration: create a mapping given the same as drug registration and the id of each of the drugs in the ordered consignment—getters for the mappings to check drugs' and orders' existence and get their details.
- **ChangeOwnership** has a simple purpose: to manage the drug and order transfer between interested parties. Since we use IDs (Ethereum address) on the ownership transfer operation, we have a method for manufacturers to register their "initial ownership" and a second method to change the ownership to other parties. We also defined two events, TransferDrugOwnership and TransferOrderOwnership. Events are logged with transactions, which is the core of our "tracking" functionality.

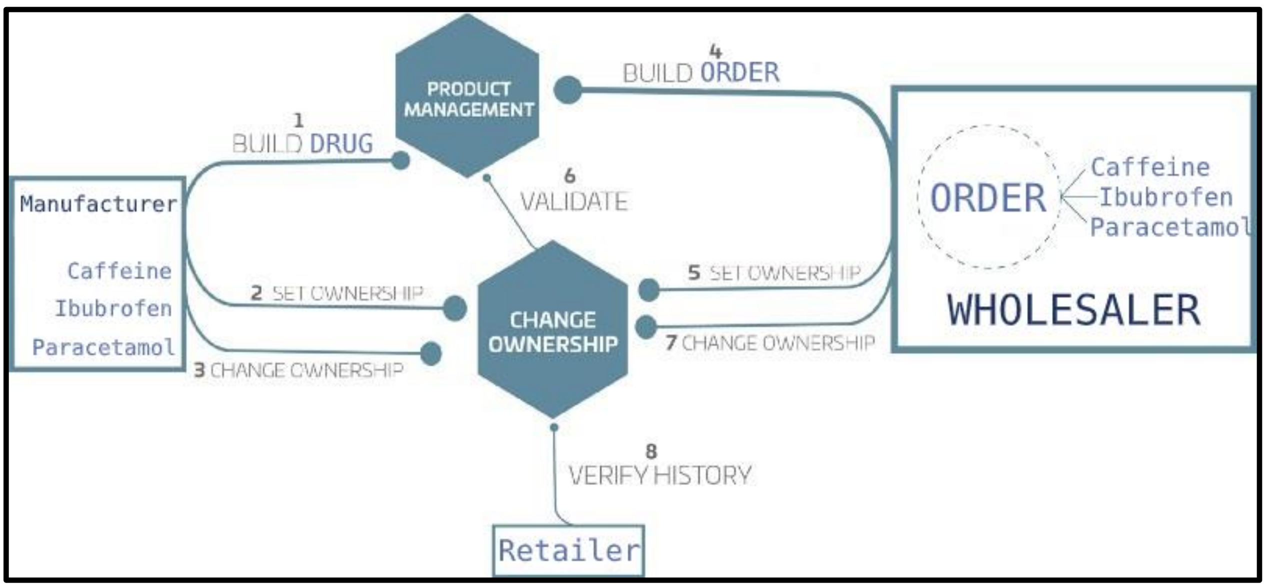


Fig 5.2: Smart Contracts Logic

5.2 Working of Node

We have built a prototype supply chain model on our local network with the following specifications. Supply chain members, such as manufacturers, wholesalers, and retailers, form our blockchain consensus network. An Ethereum node sustains each organisation. Consumers can only query the information but do not take part in blockchain consensus. The main working routine of the distributed network is as follows:

1. Each organisation's node generates its own unique and new transaction data and propagates it through peer-to-peer blockchain networks.
2. Every node generates new blocks according to the ethereum consensus algorithm.
3. Among all nodes, the first one to finish the hash calculation and signature earn the right to broadcast its results and record this transaction.
4. The node that wins the right to record the transaction by being the fastest broadcasts the new block to the entire network
5. All the other nodes receive the new block. After the information verification, they append the new block to the end of their local blockchain.

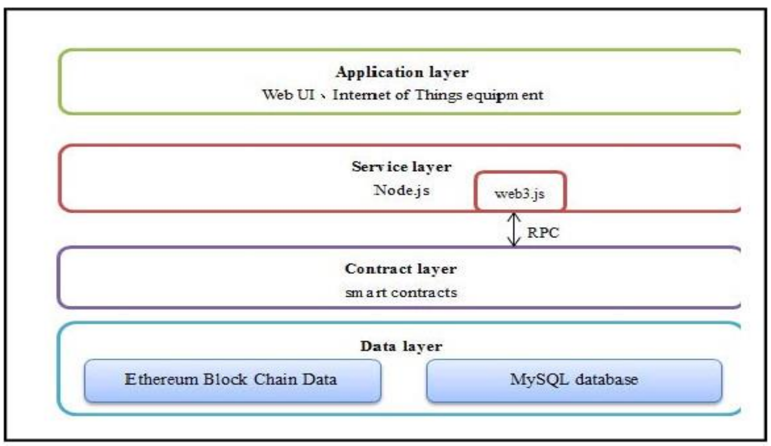


Fig 5.3: System Logic Architecture

The developed prototype application consists of four layers: application layer, service layer, contract layer, and data layer. The application layer sustains the graphical user interface; the service layer provides web services using Node.js. The contract layer exercises control over blockchain data and database data using solidity coded smart contracts. The data layer includes storage for blockchain data. The service layer's design and working layer, contract layer, and mutual interaction are crucial for this supply chain management system. The Node.js in the service layer is the backbone that supports the whole application. Node.js, recommended by the Ethereum development team, is used here to ascertain compatibility with the web interface. The smart contracts can directly contact the Ethereum blockchain over the browsers. The service layer brings better scalability and sustainability. The smart contracts residing on the contract layer interact with the Ethereum blockchain to retrieve data like timestamps, transaction history and block information from the Ethereum blockchain. The cryptographic function provided by the Solidity language facilitates data verification.

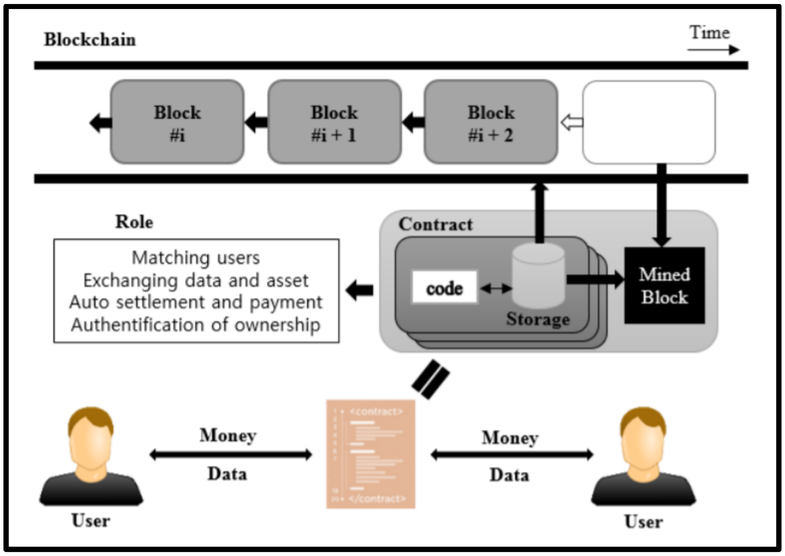


Fig 5.4 Block Addition via Blockchain[51]

5.3 Metamask

MetaMask is a cryptocurrency wallet used to communicate with the Ethereum blockchain. Allows users to access their Ethereum wallet using a browser extension or mobile application, which can work with legitimate applications. MetaMask will enable users to store and manage account keys, stream transactions, send and receive cryptocurrencies and tokens based on Ethereum, and securely connect to legitimate applications using the compatible web or mobile app's built-in browser. We have chosen metamask to be an intermediary for processing transactions between users and smart contracts. It works as an Ethereum wallet for users, allowing them to store and send any standard Ethereum. Using MetaMask to send Ether and tokens on a TestNet is straightforward; in the top-left of MetaMask, you can select an Ethereum network. Switch from the Main Ethereum Network to Ropsten (or other TestNet), and you should see your balances and transaction history update to reflect the network you've selected.

5.4 Ethereum Faucet

To interact with our blockchain network, there are two primary requirements:

- Metamask Wallet
- Ropsten TestNet Ether

Users can avail themselves of both of these requirements for free from the internet. However, acquiring Ropsten TestNet ether could be troublesome. To transact on our blockchain network, the user needs a total of 0.01 ETH at max. Our network automatically transfers 0.01 Eth to the user's metamask wallet from our privately developed ethereum faucet.

5.5 Network Deployment

- Hosting:- Web Hosting is an online service that enables you to publish your website on the internet. We have hosted our website using Netlify.
- Custom Domain:- When a user types a domain name in the address bar of the browser, the hosting service transfers all the files necessary to serve that request, and the website is visible on that address (ex. www.blockpharma.ml)
- Continuous Deployment:- The GitHub repository of the source code is attached to the deployment server. With every commit, new changes are automatically reflected on the set domain of the website.

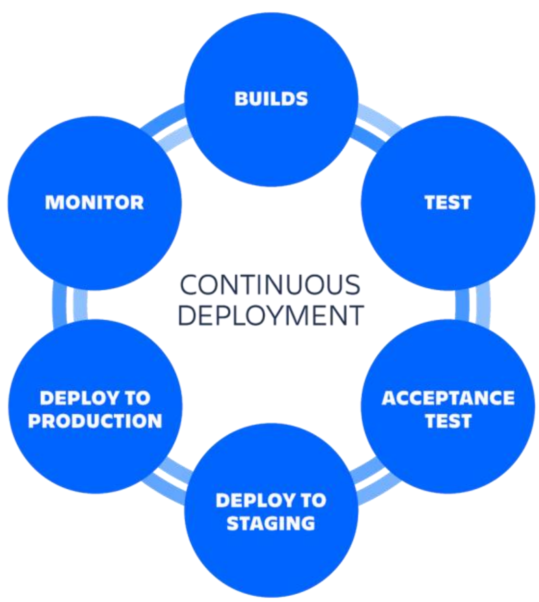


Fig 5.5: Continuous Deployment

Chapter 6: SECURITY

6.1 User Authentication

Only the user authenticated by the system is allowed to access the website.

6.2 Metamask Authentication

Only those users are allowed to do the transactions which Metamask authenticatesSecured.

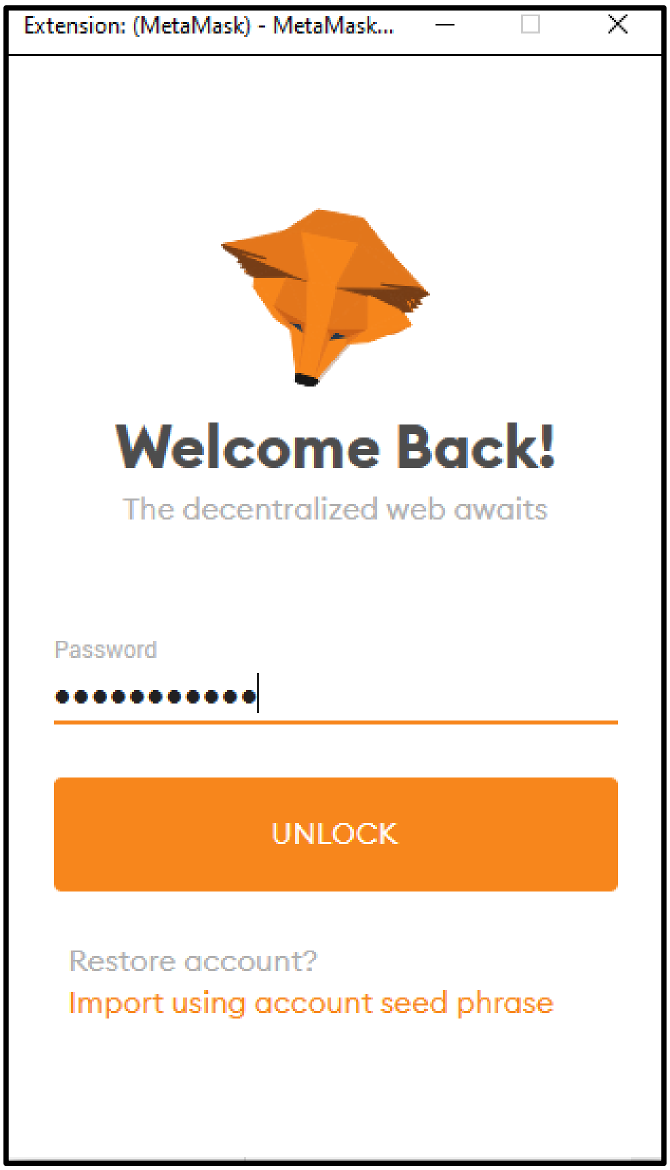


Fig 6.1 Metamask Wallet

6.3 HTTPS Certificate

HTTPS stands for Hypertext transfer protocol secure and provides a higher level of security using encryption for data transfer.

6.4 SSL Certificate

SSL or Secure Socket Layer provides a secure connection to the browser. As soon as a secure connection is established, all web traffic between the web and the browser and the webserver will be protected.

CHAPTER 7: TESTING

Testing is broadly of two types:-

7.1 Functional Testing

Functional testing serves as a quality assurance process and black-box testing that has its test cases based on the specifications of the software parts under test. Functions are tested by giving them input and analysing the output, and internal program structure is often not considered. Functional testing is conducted to analyse and evaluate the compliance of a system or component with specified applicable requirements. Functional testing usually describes *what* a system does.

7.1.1 Unit Tests

Unit Testing is a procedure of computer programming used for software testing through which individual modules along with the control data, usage and operating procedures are tested for their fitness for use.

These tests are generally automated and created by software developers to ensure the functionality of modules (also called ‘units’). Units should also follow their intended designs. Test-Driven Development (TDD) provides extreme programming scenario and improves code quality. In TDD, tests are created before writing the development code; only when the tests pass, code is considered complete. This approach helps in identifying the critical bugs early in the development process.

Unit tests enabled testing the behaviour of:

- Transaction functions
- Access control rules
- Queries

All the transaction functions were tested thoroughly, making sure to include tests for the expected exception paths. The adding and updating of assets was also tested using different identities to ensure the access control rules behaved as expected. An example of an exception path would be expecting an exception to occur if a participant attempts to update an asset they do not own. Finally, We tested the traceability capabilities of the system through testing the queries.

7.1.2 Graphical User Interface (GUI) Testing

In software engineering, **graphical user interface testing** tests a product's graphical user interface to ensure it meets its specifications. This is done through the use of a variety of test cases.

7.1.3 Integration Tests

Integration testing is the phase during which individual software modules are tested as a group. Integration testing is conducted to analyse and evaluate the compliance of a system or component with specified functional requirements. It occurs after unit testing. Integration testing takes its input as modules that have been unit tested, aggregates them in larger groups, applies tests defined in an integration test plan to those groups, and delivers its output as the integrated system ready for system testing.

Integration Testing ensures the proper working of business logic flow and the following functions of the website works as intended:-

- Website loads properly
- Login/Signup integrates with the database
- Submit Button loads the Manufacture Page
- Manufacture, Wholesaler and Retailer Page are interconnected
- Metamask authentication and integration works
- On medicine registration, ethers are deducted safely and successfully from the wallet.
- Manufacturers can transfer drugs successfully to the wholesaler’s address
- Wholesalers can create consignments from the received medicines
- Order’s Units can be transferred to Retailer
- Users can trace orders back to their origin

7.2 Non-Functional Testing

Non-functional testing evaluates a software application or system for its non-functional requirements: how a system operates, rather than specific system behaviours. This contrasts with functional testing, which pushes against functional requirements that describe a system’s functions and components. Many non-functional tests are frequently used interchangeably because of the overlap in various non-functional requirements. Like, software performance is a broad term that includes many specific requirements like reliability and scalability.

7.2.1 Compatibility Testing

Compatibility Testing checks if the software can function on different hardware, operating systems, applications, network environments or Mobile devices.

- **OS Compatibility**:- It checks whether your application is compatible with different operating systems like Windows, Unix, macOS, etc.

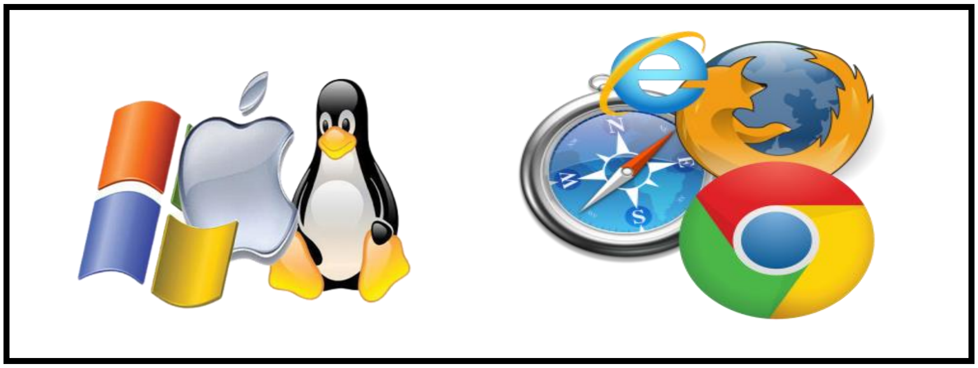


Fig 7.1 Compatible Browsers[52]

- **Browser Compatibility**:- It checks the compatibility of your website with different browsers like Firefox, Google Chrome, Microsoft Edge, etc.
- **Versions Compatibility**:- It verifies the compatibility of the website with different versions of the browsers, like Firefox 87.0, Firefox 86.0.1, Firefox 86.0, etc., and OS like Windows 10, Windows 8, Windows 7, Windows XP, etc.

Tools Used:- BrowserStack, Selenium

As seen in the below figure, selenium is used to import driver for opening the desired website and sending authentication requests. In the dictionary, desired_cap required os name, os version, browser name, browser version, and selenium version can be added for simulating the environment and executing the desired test scripts. In the below code, username and passwords are sent to test the authentication system and working of the sign-in button.

```
from selenium import webdriver
from selenium.webdriver.common.keys import Keys
from selenium.webdriver.common.desired_capabilities import DesiredCapabilities

desired_cap = {
"os" : "Windows",
"os_version" : "10",
"browser" : "Firefox",
"browser_version" : "latest-beta",
"browserstack.local" : "false",
"browserstack.selenium_version" : "3.5.2"
}

driver = webdriver.Remote(
command_executor='https://<<user>>:<<user.keys>>@hub.browserstack.com:80/wd/hub',
desired_capabilities=desired_cap)

driver.get("https://blockpharma.ml/")
if not "Block Pharma Login Page" in driver.title:
raise Exception("Unable to load Block Pharma Login Page!")

element1 = driver.find_element_by_id("email")
print("Element 1 is visible? " + str(element1.is_displayed()))
element2 = driver.find_element_by_id("password")
print("Element 2 is visible? " + str(element2.is_displayed()))
element3 = driver.find_element_by_id("signIn")
print("Element 3 is visible? " + str(element3.is_displayed()))
element1.send_keys("abc@gmail.com")
element2.send_keys("abcdef")
from selenium.webdriver.common.action_chains import ActionChains
action = ActionChains(driver)
action.click(on_element = element3)
action.perform()
driver.quit()
```

Fig 7.2: Compatibility Testing Code

7.2.2 Load Testing

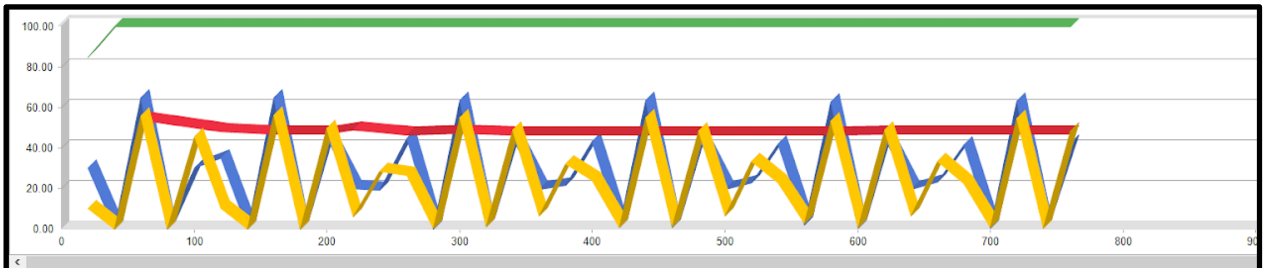
Load testing refers to the practice of modelling the expected usage of a software program by simulating users accessing the program concurrently.

Fig 7.3 Features of our Product[47]

Components of Load Testing includes:

- Hits per second
- Throughput
- Round Time:

- Load Size



Se...	Generator Name	Measurement Name	Measurement Type	Value	Min	Max	Average	Stdev	Scale
	Total	Load Size	Current Slice Sum (Current Value)	50.000	42.524	50.000	49.803	1.197	50.000
	Total	Hits Per Second	Current Slice Sum (Current Value)	21.150	0.000	32.500	13.763	11.315	50.000
	Total	Round Time	Current Slice Average (Current Value)	46.856	46.476	53.716	47.187	1.505	100.000
	Total	Throughput (Bytes Per Second)	Current Slice Sum (Current Value)	2438454.150	0.000	2808661.100	1184845.933	1082163.807	5000000.000

Fig 7.4 Load Testing Parameters

7.2.3 Transaction Latency

A Decentralized Application must operate with the lowest possible latency. Latency is lag. Low latency gives the user a favourable experience while using the same.

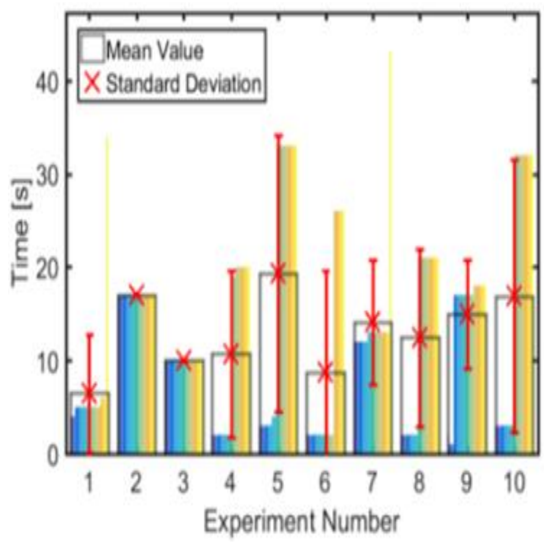


Fig 7.5: End to End Transaction Acceptance Latency

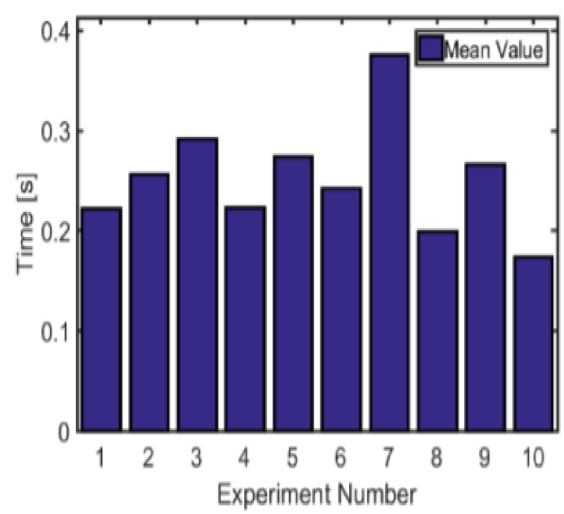


Fig 7.6 Account Balance Query Latency

7.3 Cost Analysis

There are four major categories of transactions majorly done on our blockchain network. This includes:

- Registration of drug by the manufacturer on our network
- Taking ownership of the drug registered by manufacturer
- Transferring ownership of drug from manufacturer to wholesaler
- Registration of a consignment by the wholesaler on our network
- Taking ownership of the consignment registered by wholesaler
- Transferring ownership of the consignment from wholesaler to retailer

The price of Ethereum as of May 02, 2021 is USD 2926.7 or INR 2,16,884.20. Following table represents the cost wise analysis of all the transactions on our blockchain network.

S.No	Task	Cost (ETH)	Cost (INR)
1)	Registration of drug by the manufacturer on our network	0.000002482	0.537919
2)	Taking ownership of the drug registered by manufacturer	0.000002482	0.537919
3)	Transferring ownership of drug from manufacturer to wholesaler	0.000001286	0.278801
4)	Registration of a consignment by the wholesaler on our network	0.000003414	0.739956
5)	Taking ownership of the consignment registered by wholesaler	0.000003414	0.739956
6)	Transferring ownership of the consignment from wholesaler to retailer	0.000000985	0.213443
	Total	**0.000014063**	**3.0478**

CHAPTER 8: Discussions and Outcomes

Pharma Blockchain solutions like this call for the evolution of the traditional supply ledger to a digital one. Using a pharma blockchain-based solution enables streamlined visibility of movement and stakeholders via drugs or medicines transit in the pharmaceutical supply chain. The enhanced traceability facilitates the optimised flow of goods and contributes to an efficient stock management system. Blockchain can trace the procuring and shipping of drugs and other medicinal products throughout the supply chain. Also, it is possible to pinpoint the actors or stakeholders involved on both ends in the chain of shipment. If any discrepancy arises during the supply of medicinal products or drugs, blockchain can quickly identify the last stakeholder who had the ownership of the product.

8.1 Applications

This product finds its application in the pharmaceutical level at both industrial level or a central level depending upon who sets up the blockchain network:

1. Industrial Level: In this scenario, our product, if enforced by an individual firm, would help it improve its supply chain, and the increase will help the organisation to tackle significant challenges like counterfeits, drug shortages and opioids. All this with lesser paperwork, ergo, less hassle and resource requirement.
2. Central Level: In this scenario, our product will be enforced by a central agency like the Government of India or the Indian Drug Manufacturers' Association (IDMA). A blockchain application can enable clear visualisation of a health product's journey from manufacturer to patients with digitised transactions. Therefore, it takes less effort to examine the vulnerable points in the supply chain and lessen the chances of frauds. The pharmaceutical supply chain's transaction data is maintained by the ethereum blockchain, which is consensus-driven, immutable and transparent. A blockchain-based solution has the potential to replace the governance model of the pharmaceutical supply chain from regulation to surveillance net. As such, every stakeholder can survey the supply chain data.

8.2 Future Work

Difficulties due to pandemic led to project timelines being pushed back. With more time, another supply chain model could be implemented using the same technology. More roles could be included between the manufacturer and retailer that could mimic the pharmaceutical supply chain better. Implementing multiple network models would improve the system's generalisation to a broader variety of supply chain use cases by implementing multiple network chain models. Better aesthetic and more user-friendly UI would be an added advantage. Another feature added to the project would be deployment on a shared cloud infrastructure platform such as Microsoft Azure or Amazon Web Services. This would allow organisations to implement the software with higher-end hardware and provide a more secure, enterprise-ready system.

CHAPTER 9: CONCLUSION

In this project, we explored the challenge of drug traceability within the pharmaceutical supply chain, highlighting its importance, especially in protecting against counterfeit medicines. We developed and tested a blockchain-based solution for the pharmaceutical supply chain to trace drugs in a decentralised manner. Specifically, our proposed solution leverages the basis of blockchain technology, i.e., cryptographic fundamentals, to achieve immutable logs of events within the supply chain. It utilises smart contracts within the Ethereum blockchain to create an automated record of events that are accessible to all stakeholders.

We have shown that our proposed solution saves costs in terms of the amount of gas spent on various activities due to a smart contract. The security analysis conducted has shown that our proposed solution finds protection against malicious attempts towards integrity, access to, and non-disclosure of transaction data crucial to complex multi-party planning such as the pharmaceutical supply chain.

We continue our efforts to enhance the efficiency of pharmaceutical supply chains. We envision focusing on extending the proposed system to achieve end-to-end transparency and verifiability of drug use as future work.

CHAPTER 10: BIBLIOGRAPHY

1. Lucinda Shen [2018], ‘Ethereum Regains Title as Second Most Valuable Cryptocurrency Behind Bitcoin’, Fortune.
2. Bloomberg [2020], ‘Ethereum Races Clock to Collect Enough Coins for Big Upgrade’, Bloomberg.
3. Bloomberg [2020], ‘Ethereum Becoming More Than Crypto Coder Darling, Grayscale Says’, Bloomberg.
4. Tapscott, Don Tapscott, Alex [2016]. ‘The Blockchain Revolution: How the Technology Behind Bitcoin is Changing Money, Business, and the World’, Penguin Books Limited.
5. Foundation Ethereum [2015], ‘Ethereum Launches’, Ethereum.org.
6. Finney, Gavin [2018], ‘Ethereum: Beginner's Simplified Guide to Make Money with Ethereum’, E.C. Publishing.
7. Maldonado, Fatima[2018], ‘Introduction to Blockchain and Ethereum: Use Distributed Ledgers to Validate Digital Transactions in a Decentralized and Trustless Manner’, Packt Publishing.
8. Blackburn, Christopher [2020], ‘Bitcoin And Ethereum Cryptocurrencies: 2 Manuscripts - Bitcoin Explained AND Ethereum Blockchain Revolution Explained’.
9. Popular Timelines [2021], ‘History of Ethereum in Timeline’, Popular Times.
10. Nomoneytimes [2020], ‘What is Ethereum’, Nomoneytimes.
11. Ethereum [2020], ‘Consensus mechanism’, Ethereum.org.
12. Noama Samreen [2020], ‘Querying data in an Ethereum Blockchain’, Medium.
13. OpenZeppelin Docs [2020], ‘Access Control’, OpenZeppelin.
14. Bloomberg [2020], ‘Ethereum Upgrade Adds to Crypto Mania Sparked by Bitcoin's Surge’, Bloomberg.
15. Varshney, Neer [2018], ‘Ethereum's supply has crossed 100M, here's what that means!’, The Next Web.
16. EthDocs Org [2020], ‘Account Types, Gas, and Transactions’, EthDocs Org.
17. SolidityLang Org [2020], ‘Introduction to Smart Contracts’, SolidityLang.
18. Wood, Gavin [2018], ‘Ethereum: A Secure Decentralized Generalised Transaction Ledger (EIP-150)’, Ethereum Project Yellow Paper.
19. Ethereum Homestead [2020], ‘Account Types, Gas, and Transactions’, Ethereum.org.
20. Musamih, Ahmad & Salah, Khaled & Jayaraman, Raja & Arshad, Junaid & Debe, Mazin & Al-Hammadi, Yousof & Ellahham, Samer. [2021], ‘A Blockchain-Based Approach for Drug Traceability in Healthcare Supply Chain’, IEEE Access
21. Francis Boily [2018], ‘Explaining Ethereum Test Networks And All Their Differences’, Medium.
22. Johnson, Steven [2018], ‘Beyond the Bitcoin Bubble’, The New York Times.

23. Schroeder, Stan [2020], ‘Crypto wallet MetaMask finally launches on iOS and Android, and it supports Apple Pay’, Mashable.
24. Leising, Matthew [2020], ‘MetaMask's Blockchain Mobile App Opens Doors For Next-Level Web’, Bloomberg News.
25. Jaffe, Justin [2020], ‘How to keep your cryptocurrency safe’, CNET.
26. ISO/IEC/IEEE International Standard [2010], ‘Systems and software engineering’, ISO/IEC/IEEE 24765:2010(E).
27. Martyn A Ould & Charles Unwin (ed) [1986], ‘Testing in Software Development’, BCS.
28. Kaner, Falk, Nguyen [1999], ‘Testing Computer Software’, Wiley Computer Publishing.
29. Regattieri, A., Gamberi, M. and Manzini, R. [2007], ‘Traceability of food products: General framework and experimental evidence’, Journal of Food Engineering.
30. ISO [2015], ‘Quality Management Systems — Fundamentals and Vocabulary’, ISO 9000:2015(En).
31. Thakur, M., Sørensen, C.-F., Bjørnson, F. O., For˚as, E. and Hurburgh, C. R. [2011], ‘Managing food traceability information using EPCIS framework’, Journal of Food Engineering.
32. Moe, T. [1998], ‘Perspectives on traceability in food manufacture’, Trends in Food Science & Technology.
33. Jansson, F. and Peterson, O. [2017], ‘Blockchain Technology in Supply Chain Traceability Systems’, Lund University.
34. Golan, E., Krissoff, B., Kuchler, F., Calvin, L., Nelson, K. and Price, G. [2004], ‘Traceability in the US food supply: Economic theory and industry studies’, Agricultural economic report.
35. Yiannis, F. [2017], ‘Genius of Things: Blockchain and Food Safety with IBM and Walmart’, Internet Of Things.
36. Kivi, M., Hofhuis, A., Notermans, D. W., Wannet, W. J. B., HECK, M. E. O. C., Van De Geissen, A. W., Van Duynhoven, Y. T. H. P., Stenvers, O. F. J., Bosman, A. and Van Pelt, W. [2007], ‘A beef-associated outbreak of Salmonella Typhimurium DT104 in The Netherlands with implications for national and international policy’, Epidemiology and Infection.
37. Aung, M. M. and Chang, Y. S. [2014], ‘Traceability in a food supply chain: Safety and quality perspectives’, Food Control.
38. Bechini, A., Cimino, M. G., Marcelloni, F. and Tomasi, A. [2008], ‘Patterns and technologies for enabling supply chain traceability through collaborative e-business’, Information and Software Technology.
39. Chainpoint [2020], ‘Supply Chain Traceability’, Chainpoint.
40. Sohail Jabbar, Huw Lloyd, Mohammad H., [2020], ‘Blockchain-enabled supply chain: analysis, challenges and future directions’.

41. Soundarya K., Priyanka Pandey, R. Dhanalakshmi, [2018], 'A Counterfeit Solution for Pharma Supply Chain', EUDL.
42. Guru99 [2021], 'What is Compatibility Testing? Forward & Backward Testing', Guru99.
43. Techtutorialz [2018], 'Non functional testing - Non functional testing types', Techtutorialz.
44. Cogniron [2021], 'Functional Testing', Cogniron Technologies.
45. LeewayHertz [2021], 'Blockchain in Pharma Supply Chain - Reducing Counterfeit Drugs', LeewayHertz.
46. G2 [2021], 'Best Blockchain Software in 2021', www.G2.com.
47. Parveen [2019], 'Continuous Load Testing Tools and Features', XenonStack.
48. Minjae Yoo, Yookae Won[2018], 'A study on the Transparent Price tracking system in Supply Chain Management Based on the blockchain', MDPI.
49. Chen, E. [2016], 'An Approach for Improving Transparency and Traceability of Industrial Supply Chain with Blockchain Technology', University of Tampere.
50. Manfye. [2017], 'The Future of Healthcare in Blockchain Technology', -Steemit
51. Yoo, Minjae & Won, Yoojae. (2018). A Study on the Transparent Price Tracing System in Supply Chain Management Based on Blockchain. Sustainability. 10. 4037. 10.3390/su10114037
52. Revathy N. [2021], 'Google Chrome Vs. Microsoft Edge: What to Choose in 2021?' - BrowserHow

APPENDIX

A.1 Operating the website

A.1.1 Sign In Webpage

- User's need to first make an account using the signup button.
- After making the account user can sign in to the website.

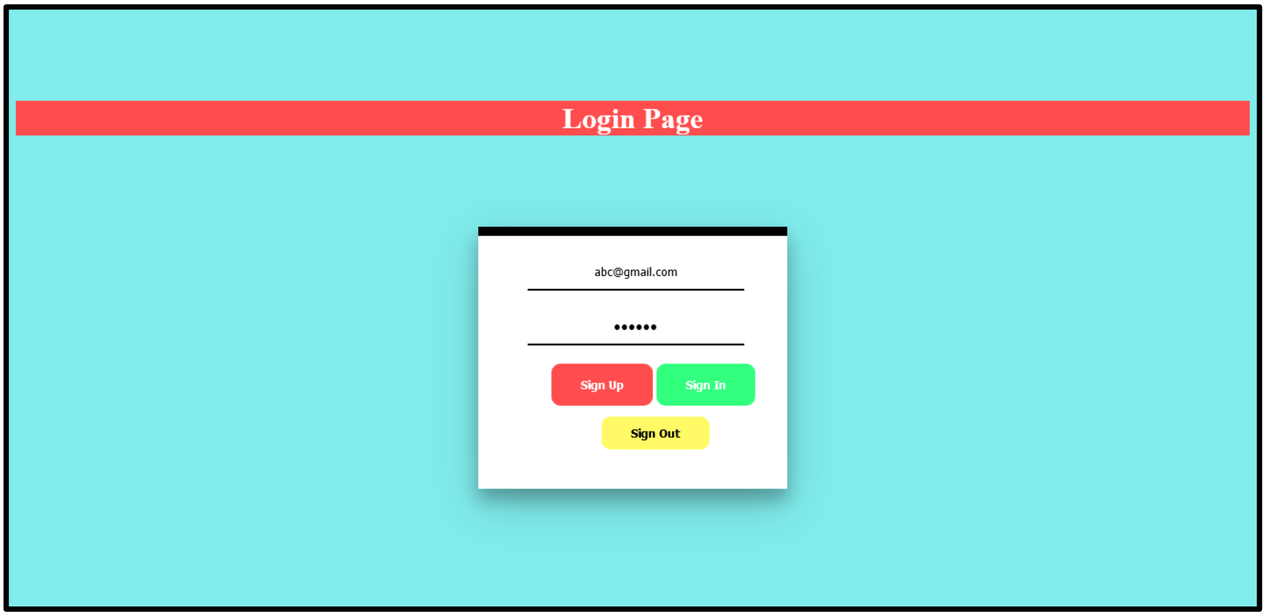


Fig A.1: User Login Page

A.1.2 Manufacturer Webpage

- The manufacturer can register the manufactured drug through this webpage.
- The manufacturer needs first to enter the drug serial number and the drug type.
- The subsection **'Drugs Owned'** shows the drugs which the manufacturer registers.
- The manufacturer can transfer the ownership of the drugs to the wholesaler by entering the wholesaler account address.
- Both the process of manufacturing drug and changing ownership will require the confirmation of MetaMask wallet.

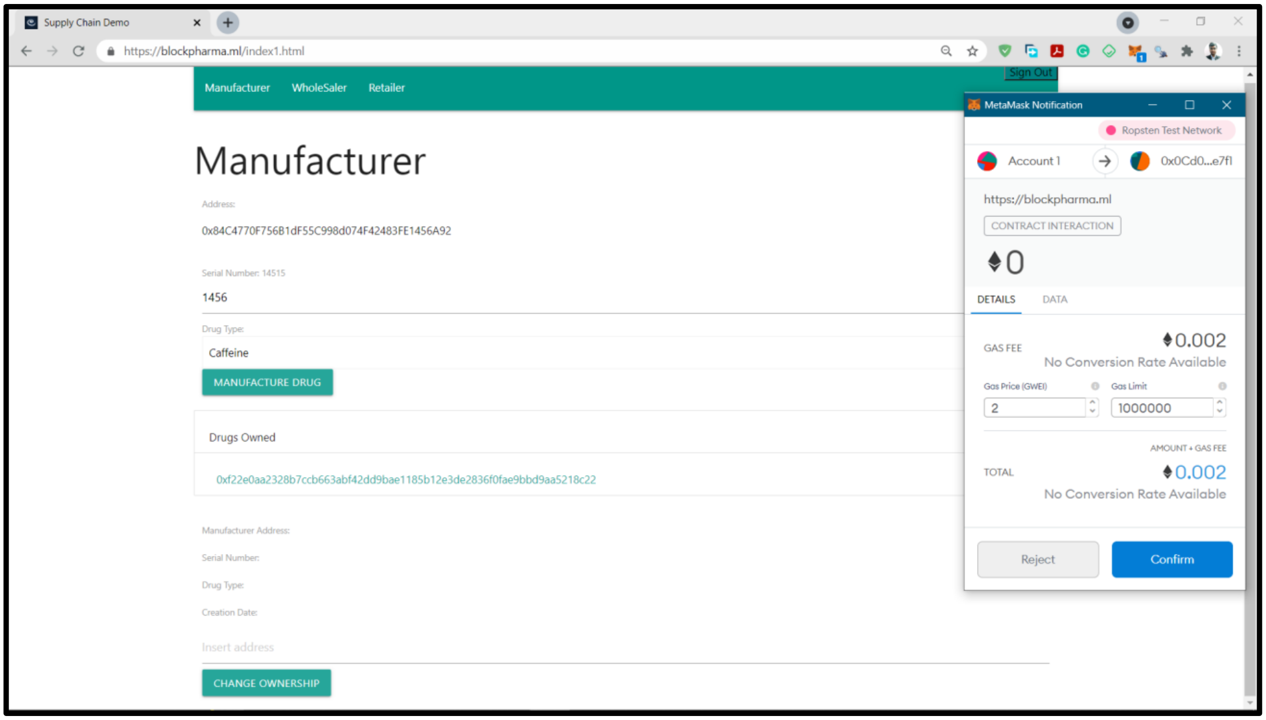


Fig A.2: Manufacturer Registration Page

A.1.2 WholeSaler Webpage

- The wholesaler can view the drugs he possesses on the left upper subsection **Drugs Owned.**
- Using the wholesaler's drugs, he will register a batch of drugs using the **Create Order** button.
- After the batch of drugs has been registered, the wholesaler can transfer the ownership of the order to the retailer using the **Change Ownership** button.
- Both the process of Crete Order and Changing Ownership will require the confirmation of MetaMask wallet.

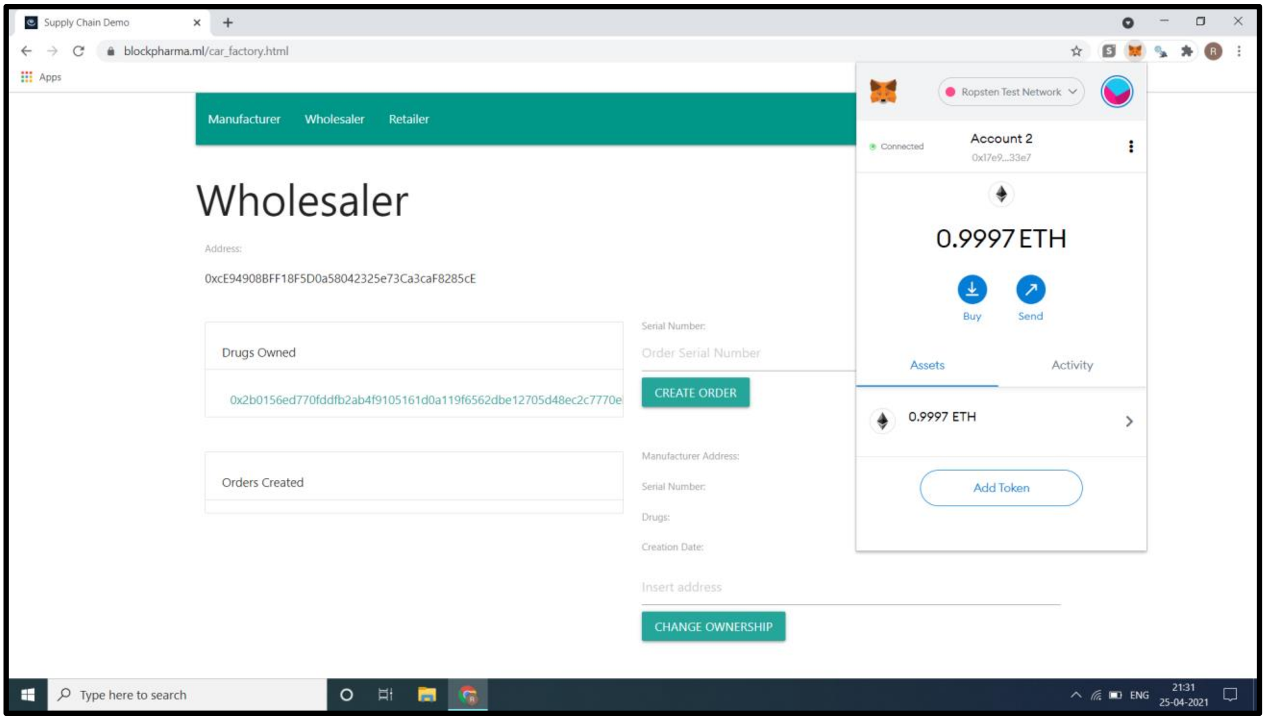


Fig A.3: Wholesaler Registration Page

A.1.3 Retailer Webpage

- The retailer can view the complete history of the product on this webpage.
- The subsection **Order History** displays the drugs which he possesses. **Owner History** below shows who was the previous owner or the wholesaler address.
- The subsection **Drugs History** displays the raw materials used to manufacture the drug, and the **owner history** shows the address of the raw materials manufacturer.

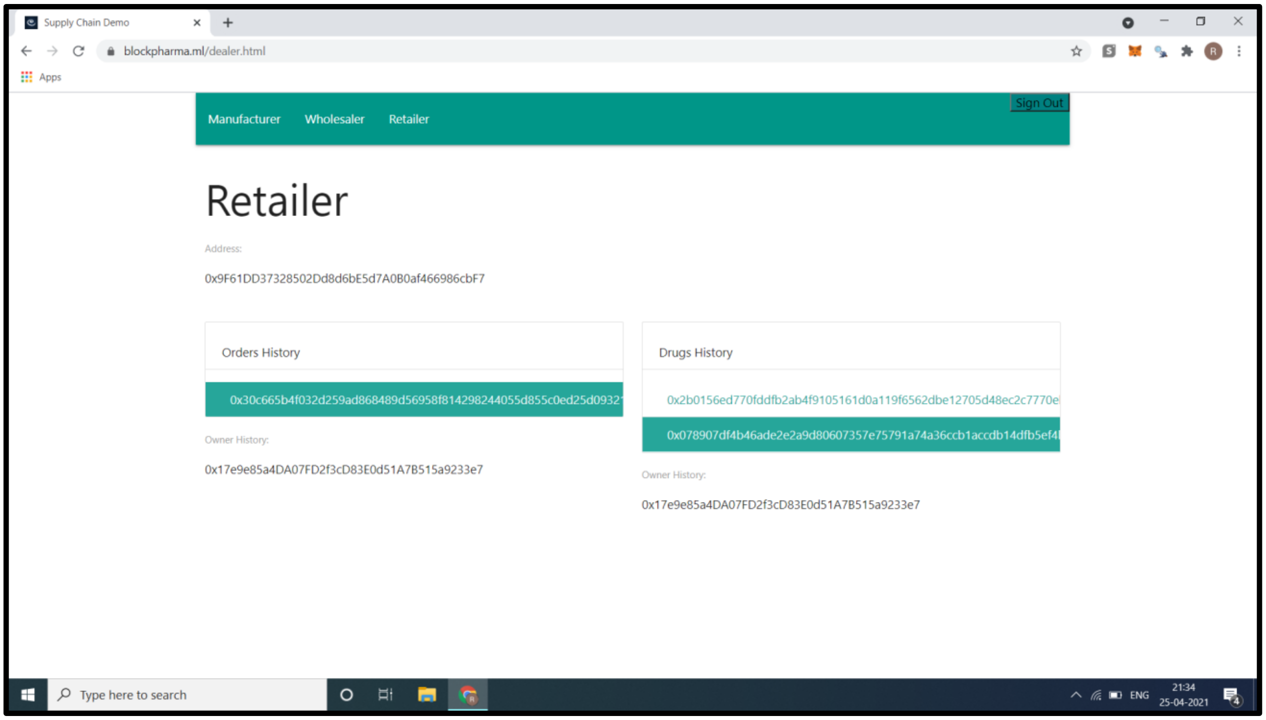


Fig A.4: Retailer Registration Page

A.1.4 Blockchain

The image below shows a list of blocks created during blockchain deployment.

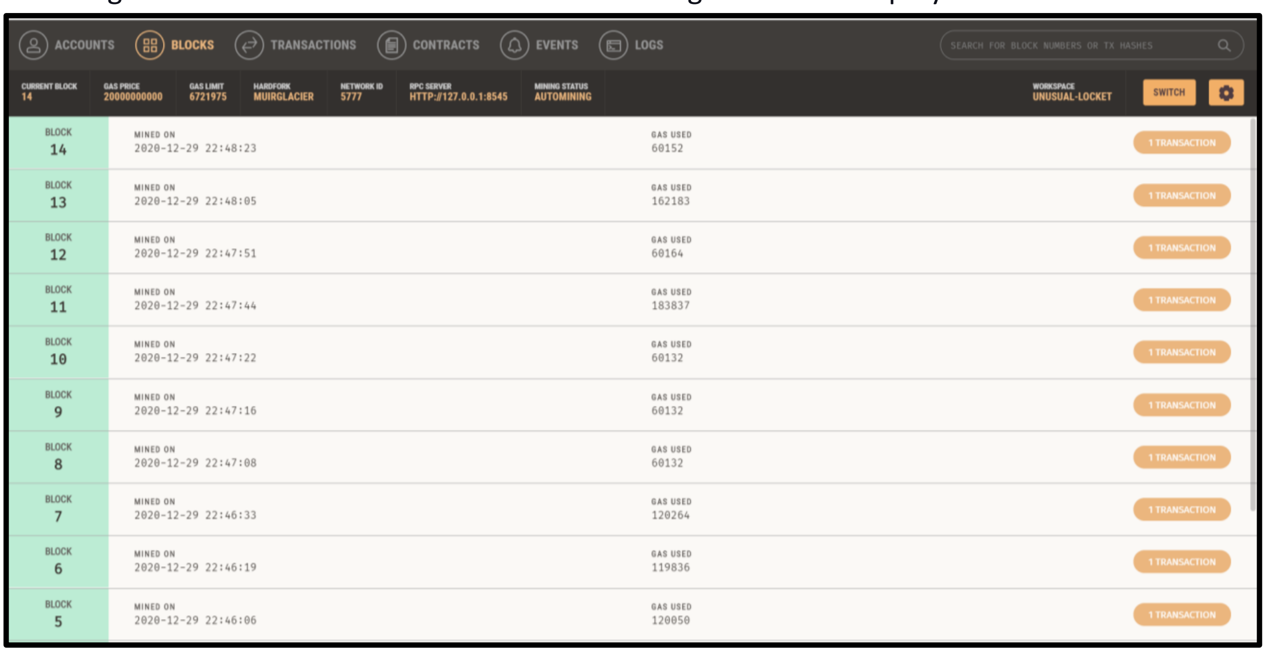


Fig A.5: Blocks created in the BlockChain

Every transaction in the blockchain is marked with a signature and transaction hash. The image below depicts the transactions that took place in the blockchain during our test deployment.

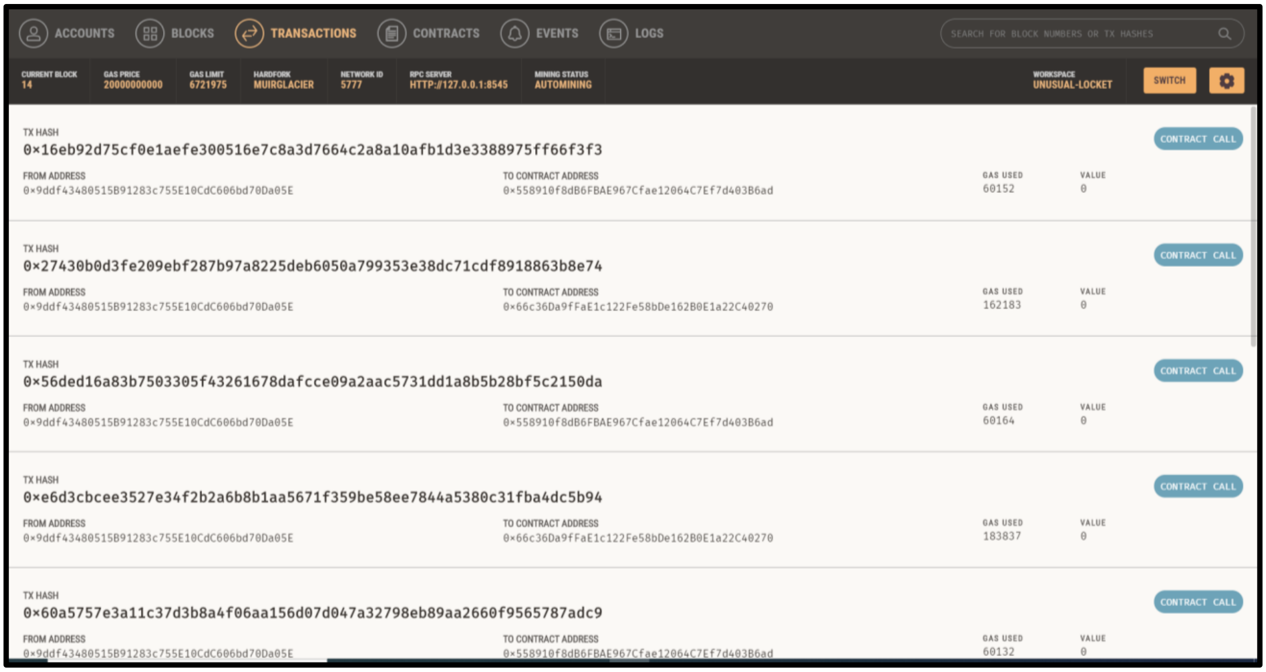


Fig A.6: Transactions Occurred