Monitoring Supply chain of pharmaceutical drugs using blockchain.

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ABSTRACT

Counterfeit medicines pose a serious threat due to the shortage of medicines and lack of transparency in the supply chain. Investigating illegal or unethical practices is difficult. To address this issue, this paper proposes a system that merges Blockchain and AI technologies. Blockchain provides a decentralized, distributed, transparent, and immutable ledger that can efficiently record transactions between parties, making it easy to solve the problem of counterfeit medicines. AI improves customer service and enables easy access to blockchain-based medical technologies. The proposed system uses smart contracts to record transactions between authenticated entities, making it possible to trace a product back to its source. The DApp, developed using the React framework, is connected to the blockchain using Web3.js and the Truffle framework. The proposed system that merges Blockchain and AI technologies has the potential to revolutionize the pharmaceutical industry by making the supply chain more transparent and secure. Counterfeit medicines can be dangerous and ineffective, putting people's health at risk. With this system, it becomes easier to detect and prevent the distribution of counterfeit drugs. By using smart contracts to record transactions between authenticated entities, the proposed system provides an efficient and reliable way to trace a product back to its source. This can help to ensure the authenticity and quality of medicines, providing greater confidence for patients and healthcare providers alike. Additionally, the use of AI can improve customer service by providing easy access to blockchain-based medical technologies and supporting better medication tracking.

Keywords: counterfeit medicines, lack of transparency, supply chain, blockchain, AI, decentralized, distributed, transparent, immutable, smart contracts, traceability, authentication, medication tracking, DApp, React framework, Web3.js, Truffle framework, pharmaceutical industry, healthcare providers, patient safety.

1] INTRODUCTION

The distribution of prescription medications through the pharmaceutical supply chain network is a complex process that involves multiple stages and spans over months or longer, across various regions worldwide. The supply chain comprises several entities like suppliers, manufacturers, transporters, wholesalers, distributors, retailers, and others. Tracking every medical drug throughout the chain and tracing it back to its source is challenging, and drug counterfeiting is a significant concern globally. Developing countries report nearly 10-30% of drugs are fake, and about 30% of all medication sold in Africa, Asia, and Latin America is counterfeit. The key issue with counterfeit drugs is that they can have different side effects on human health than genuine medications.

The lack of transparency in the current supply chain system makes it challenging for customers or buyers to know the value of the products. It is also challenging to investigate any tampering within the supply chain when there is suspicion of illegal or unethical practices. This inefficiency leads to difficulty for vendors and suppliers to establish links among entities and identify who needs what, when, and how. Blockchain technology can revolutionize the supply chain by providing a distributed hyperledger with no centralized authority over the system. Each transaction in the blockchain is immutable, ensuring that sensitive data like drug and customer information cannot be tampered with. Blockchain also provides complete transparency, which brings trust between various entities in the supply chain, such as manufacturers, intermediaries, and end-users.

Finally, a DApp (Decentralized App) is developed using the React Framework, and smart contracts are deployed on a private local blockchain provided by Ganache. The DApp is connected to the blockchain using Web3.js and the Truffle framework.

The rest of the paper is organized as follows. Section II states the review of literature, and Section III introduces the preliminaries used in this paper. In Section IV, the system architecture is described in detail. The smart contract's concrete implementation is exhibited in Section V, and the experiment and evaluation are discussed in Section VI. Finally, the conclusion is presented.

2] LITERATUE SURVEY

Over the years, many scholars and entrepreneurs have made many discussions and research on how to combine blockchain technology to improve and manage the current situation of the supply chain.

G. Perboli et al.[1] describes the standard methodology for developing and validating the overall Blockchain solution and de signing a strategy for integrating it into Business Strategy. They also highlight how blockchain can tackle security challenges in IoT, such as identifying different devices and managing trust, information tracking, authentication and access control, and accountability in IoT-based applications.

Jamil et al. [3] proposed an application based on a user service framework that uses smart contracts and a distributed ledger as middleware. The proposed system is based on a permissioned blockchain that allows only valid participants to participate and enroll in the blockchain network, thus separating it from the other blockchain-based systems. The proposed smart contract-based application uses the transaction and executes several queries and updates the ledger state by appending the transaction blocks, and returns the updated result as a response to the application.

Q. Zhu et al. [5] focus on linking the product deletion decision-making process, which is a process of deleting a product and all its related information from the company's portfolio with Blockchain technology. The four main stages in the product deletion process have been proposed: recognition, analysis and revitalization, evaluation and decision-making, and implementation. Blockchain technology improves communication and collaboration among various entities in the supply chain and thus increases information efficiency, effectiveness and reduces conflicts.

Prachi Shrikant et al. [6] focuses on the importance of Blockchain technology to trace and detect counterfeit products in the supply chain. Every time the medicinal drug moves from one entity to another, the information stored in the blockchain makes it easy to track the drug, and thus the threat of counterfeit products is reduced. Blockchain technology helps solve the main issues, as each new transaction is time-stamped, enabling companies to track their products in the supply chain. Allowing stakeholders to take actions in case of any issues by identifying the exact location of the drug.

K. Toyoda et al. [7] proposed the need to develop anti-counterfeit systems that will work when the RFID tag's information will be cloned in the post supply chain. Hence through the paper, they proposed The Possession of Products scheme. The counterfeits can be detected if any entity is unable to prove the possession of the particular product. They have suggested blockchain, as Bitcoin allows users to prove their ownership without the need for any authentication and centralized authority.

Huang et al. [8] narrate the importance of Drugledger, a fully scenario-oriented blockchain system for drug traceability and regulation. Drugledger uses the UTXO-based transaction model combined with the supply chain to construct the entire workflow that includes drug packaging, repackaging, unpackaging and drug transaction cancellation, the arrival and exit of the drug supply chain, and so on.

Thus, the Drugledger manages to separate the drug traceability service from data modification, ensuring data authenticity and privacy.

J. Ma et al. [9] describe the need for a fully-functional blockchain system to prevent product counterfeiting to ensure that the products can be identified and traced in the supply chain. They propose using Ethereum, a Blockchain platform and suggest that users write smart contracts using Solidity and deploy them on the network. Through the proposed anti-counterfeit system, the users do not have to be concerned regarding acquiring counterfeit products.

Leng et al. [11] proposed a public Blockchain with a double chain architecture to enhance agricultural supply chain systems' efficiency. They showed that their solution provides adaptive rent-seeking and matching mechanisms for public service platforms. It guarantees the transparency and security of transaction information and privacy of enterprise information. The main drawbacks are the size of the underlying Blockchain network and the related performance issues.

Mao et al. [12] proposed a Blockchain-based credit evaluation system to strengthen supervision and management effectiveness in the food supply chain. In particular, they gather credit evaluation text from traders by smart contracts on the blockchain. Further, the text is analyzed by a deep learning method named Long Short-Term Memory (LSTM). The system's drawback is that they show the effectiveness of their method, but they do not consider the overall system costs and benefits explicitly.

R. Kumar et al. [2] proposed a framework that represents a blockchain-based secure infrastructure for the medical supply chains among valid participants, which can provide drug security and the authenticity of the manufacturer. It is based on PKI and digital signatures to prevent replay and man-in-the-middle attacks.

3] PRILIMINARIES

This section reviews some of the relevant background knowledge and detailed concepts that will be used throughout this paper.

3.1. Blockchain

Blockchain is a new technology that is gradually emerging with the increasing popularity of digital currencies such as Bitcoin. It is essentially a distributed ledger database. Blockchain records transactions that have occurred by establishing a database maintained by all network nodes and the entire process is open, transparent, and irreversible. According to the participants, it can be divided into the public blockchain, consortium blockchain, and private blockchain, and the consortium blockchain and the private blockchain are collectively referred to as the permissioned blockchain. The public blockchain is completely decentralized in the real sense. At any time, any node will join or leave the decision to build a new block. In the permissioned blockchain, though, the decision to build a new block is made by certain trusted nodes. It has been applied to copyright management, identity authentication, and data storage services.

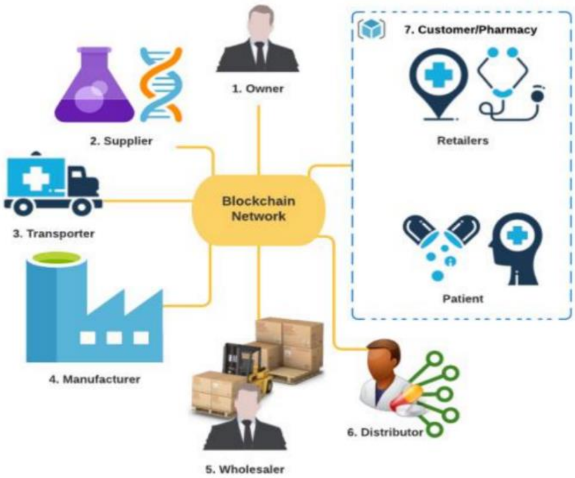
3.2. Ethereum and Smart Contracts

Bitcoin's universality is low since it is built only for virtual currency scenarios and is not Turing-complete. As a result, several other blockchain-based technologies have evolved, and various kinds of software will now be represented on the blockchain as smart contracts. Ethereum first realized the complete fit of blockchain and smart contracts. If a smart contract is deployed on the blockchain, it would be implemented in accordance with predefined rules, and no one will be able to alter it. The smart contract in Ethereum is written in a stack-based low-level bytecode language called EVM code, which is executed by the Ethereum Virtual Machine.

4] SYSTEM ARCHITECTURE

This section introduces the system model of the product traceability process, which is realized by the decentralization and data immutability of blockchain technology. In the process, any node can have both the attributes of demand and supply. In the product transaction formation process, an event response mechanism is designed in order to ensure that both parties of the transaction agree on the receipt and delivery of medical drugs. The transaction data will be permanently stored in the blockchain using smart contracts. Furthermore, we design a mobile application that is integrated with the Rasa chatbot for customer service

4.1] SYSTEM OVERVIEW



As shown in Fig., the proposed system consists of many entities like suppliers, transporters, manufacturers, wholesalers, distributors, and customers/retailers and is connected through a decentralized network. Each of the above entities of the supply chain is a node on the public blockchain. Each of these nodes has its own Ethereum account, which is used for representing its identity. The specific roles and functionalities of each are discussed below:

1. Owner

a. CREATE a new user to be added to the chain.
b. READ the information of any user.
c. UPDATE the roles of a user.
d. DELETE a user from the chain.

2. Transporter

a. Verify the package (Raw Material or Medicine).
b. Pick the package from an entity (based on transporter type).
c. Deliver the product to an entity.

3. Supplier

a. CREATE a Raw Material.
b. GET the addresses of the Raw Materials created.

4. Manufacturer

a. Receive the Raw Material from the Supplier through the Transporter.
b. Verify the source of the product received.
c. CREATE a new Medicine using received raw materials.

5. Wholesaler

a. Receive the medicine from the manufacturer through the Transporter.

b. Verify the source of the medicine.

c. Transfer the ownership of the medicine.

6. Distributor

a. Receive the medicine from the Wholesaler through the Transporter.

b. Verify the source of the medicine.

c. Transfer the ownership of the medicine.

7. Customer

a. Receive the medicine from the Distributor through the Transporter.

b. Verify the source of the medicine.

c. Place orders using the Rasa chatbot.

d. Get medical drug information.

4.2] SMART CONTRACT DESIGN

Supply Chain Contract: This contract is deployed by the Owner of the chain. It consists of many entities associated with the supply chain, i.e., Owner, Supplier, Transporter, Manufacturer, Wholesaler, Distributor, Customer. It also consists of various Solidity events used to communicate with the front end in real-time. Each function in the contract can only be accessed by its respective role assigned to it. This is done with the help of "modifiers" in Solidity. Thus, no entity without a particular role can access a specific function. This helps to increase the security and accessibility of data stored or queried from the blockchain.

Raw Material Contract: A respective Supplier deploys the Raw Material Contract. Once a raw material is created physically, it is then added to the chain by the supplier that created the raw material. While creating a raw material to be added to the chain, data such as EA (Ethereum Address) of the Supplier, DateTime, EA of Transporter, Transaction Contract Address, etc. are requested from the supplier. It also contains events that can compute the whereabouts of the package in real-time. The EA of Receiver (Manufacturer) is later updated based on the event request-response mechanism. It also stores the current status of the medicine, i.e., which entity currently has the raw material.

Medicine Contract: The respective manufacturer deploys the Medicine Contract. Once a medicine is created physically, it is then added to the chain by the manufacturer that created the medicine. While creating medicine to be added to the chain, data such as EA (Ethereum Address) of Raw Material used to create medicine, DateTime, EA of Transporter, Transaction Contract Address, etc., is requested from the manufacturer. It also contains events that can compute the whereabouts of the package in real-time. The EA of Wholesaler, EA of Distributor, and EA of Customer are updated later based on the event request-response mechanism. It also stores the current status of the medicine, i.e., which entity currently has the package.

Transaction Contract: The Transaction Contract is deployed automatically by the Raw Material and Medicine smart contracts whenever created. The contract takes data such as DateTime, sender EA, receiver EA, location, transaction hash, and the hash of the previous transaction. The transaction hash is 32 bytes. The previous transaction hash is stored for entities to verify the source of products in the chain—an example of transaction data in the smart Transaction contract.

TxnHash	From	To	Prev. TxnHash	Lat	Lng	Timestamp
0xf3...e0	0xCc...06	0x72...9D	0xf3…e0	19.07	72.81	1616358305
0xd7...5e	0xCc...06	0x9a...64	0xf3...e0	18.52	72.85	1616651750

4.3] PRODUCT TRACEBILITY AND SOURCE VERIFICATION

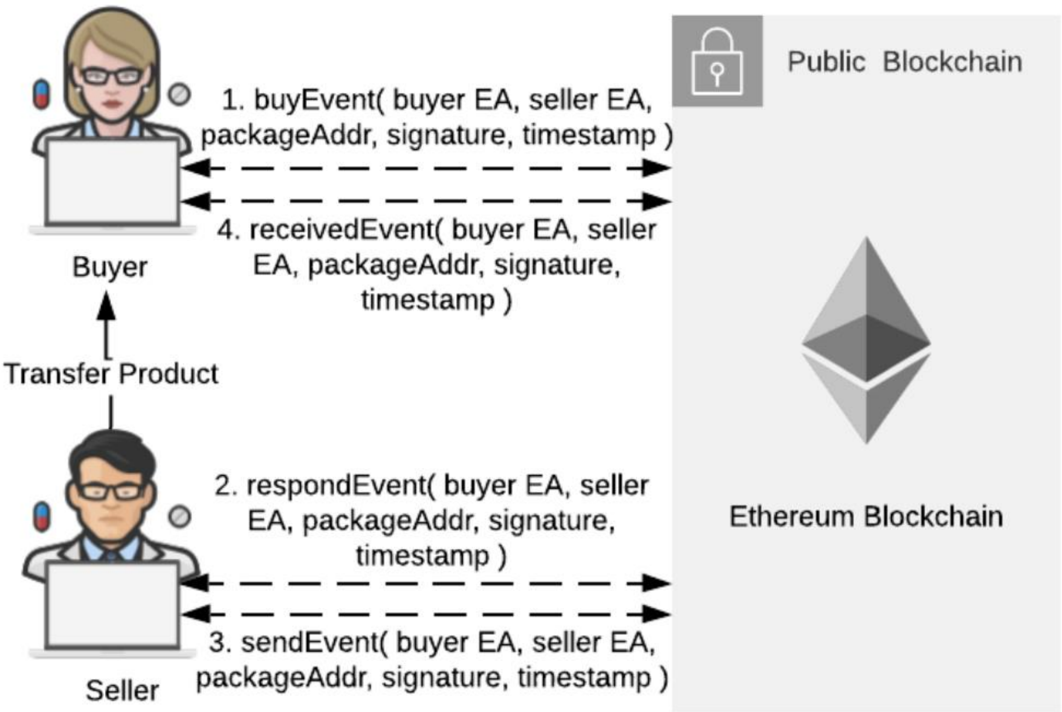


Fig.Event Request-Response Mechanism.

As shown in the above Fig. , the process of agreeing on the delivery and receipt of goods by both parties of the transaction is shown using the event request response mechanism [13]. It is discussed in detail below.

1. First, the buyer initiates a purchase request. The buyEvent() event in the Supply Chain contract is then triggered. The event includes the buyer's and seller's Ethereum address (Buyer EA and Seller EA), the address of the raw material/medicine to be purchased, along with the signature which is signed with the private key of the requester(buyer) and timestamp of the request. The signature is sent along in the events to confirm the identity of both parties and the authenticity of the request. The Seller addresses are indexed so that each seller can query their records based on their Ethereum Address.

2. Then, the Seller queries the log records related to himself according to his Ethereum address and verifies the validity of the signature contained in the events. If the verification is passed, an event

respondEvent() is triggered by the seller to respond to the buyer's request along with a signature which is signed with the private key of the seller.

3. Next, the Seller sends the product to the buyer through the Transporter. An event sendEvent() is triggered to prove that the raw materials/medicines have been shipped, including the Seller's and buyer's Ethereum address (Seller EA and Buyer EA), the product address, along with the signature which is signed with the private key of the Seller and timestamp of the transfer of the product.

4. Finally, an event receivedEvent() is triggered by the buyer upon receipt of the goods to certify that the goods have been received.

For example, suppose the manufacturer requires a raw material to create new medicine. In that case, the manufacturer acts as the buyer, and the supplier, which requires the raw material, acts as the seller. Once the above process is completed, the Supplier will update the transaction information according to the product address in the corresponding Transaction contract, and the new receiver of the raw material is updated in the Raw Material contract. The system assumes that only after both parties of the transaction have truthfully activated the above events, the transaction details will be changed. The product's source will be regarded as trustworthy.

5] SYSTEM IMPLEMENTATION

5.1] PROCESS FLOW DIAGRAM

Sr. No	**Action Description**
1	Owner deploys the smart contracts to the Ethereum Blockchain
2	The Owner authenticates and registers the entities of the chain
3	Supplier registers a new Raw Material
4	Raw Material Contract is deployed for the newly created raw material
5	Corresponding Transaction Contract is also deployed for the newly created raw material
6	Raw material registered successfully

7	Supplier transfers the raw material to the Transporter
8	Supplier updates the product status and creates a Transaction in the Transaction Contract
9	Transporter transfers the raw material to the manufacturer
10	Manufacturer verifies the source of the raw material
11	Manufacturer updates the product status and creates a Transaction in the Transaction Contract
12	Manufacturer registers a new medicine
13	Medicine Contract is deployed for the newly created medicine
14	Corresponding Transaction Contract is also deployed for the newly created medicine
15	Medicine registered successfully
16	Manufacturer transfers the raw material to the Transporter
17	Manufacturer updates the product status and creates a Transaction in the Transaction Contract
18	Transporter transfers the raw material to the Wholesaler
19	Wholesaler verifies the source of the raw material
20	Wholesaler updates the product status and creates a Transaction in the Transaction Contract
21	Wholesaler transfers the raw material to the Transporter
22	Wholesaler updates the product status and creates a Transaction in the Transaction Contract
23	Transporter transfers the raw material to the Distributor

24	Distributor verifies the source of the raw material
25	Distributor updates the product status and creates a Transaction in the Transaction Contract
26	Distributor transfers the raw material to the Transporter
27	Distributor updates the product status and creates a Transaction in the Transaction Contract
28	Distributor transfers the raw material to the Customer
29	Customer verifies the source of the medicine through a temporary node
30	Customer updates the status of the product through a temporary node

The proposed system is discussed in this section. The truffle framework [14] helps in better the compilation and deployment of smart contracts. Truffle is a development tool for the Ethereum Solidity language and provides a test framework, making DApp development easier. The test environment for the proposed solution is listed in the above Table. Visual Studio Code is a powerful, free, and open-source text editor that can build a solidity IDE by downloading some plugins. Web3.js [15] is a JavaScript library provided by Ethereum. It offers a complete set of JavaScript objects and functions that help the client side interact with the blockchain. We compile and migrate our contracts, which gives us a build version of our contracts that integrates the contract abstraction into the script to make use of the contract abstraction provided by truffle directly in the JavaScript code. The key to DApp development is to write the smart contracts and interact with them through the front-end web pages. The code for the front-end, along with the connection establishment and interaction logic, is written in JavaScript with the ReactJS framework's help. Users can interact with contracts through the UI to use the different functionalities provided by the DApp.

5.2] SYSTEM TEST ENVIRONMENT –

<u>Software Version</u>

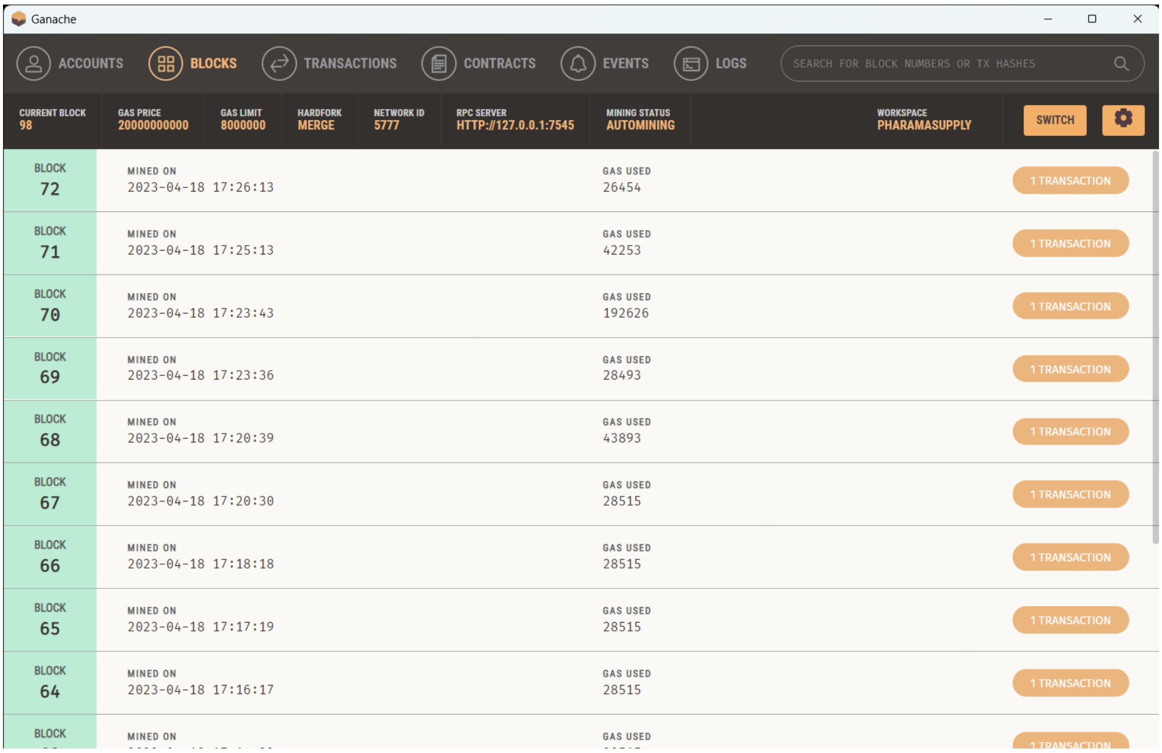
Solidity	0.6.6 or more
Ganache	2.5.3 or more
Truffle	5.1.58 or latest
Metamask	8.1.9 or lattest
Web3	1.3.1 or lattest
ReactJS	17.0.1 or more

5.3] EXPERIMENTAL RESULTS OF A SMART CONTRACT DEPLOYMENT

The smart contracts were deployed on a local blockchain provided by Ganache [16]. The contracts and the gas cost for deploying them are displayed in the table below

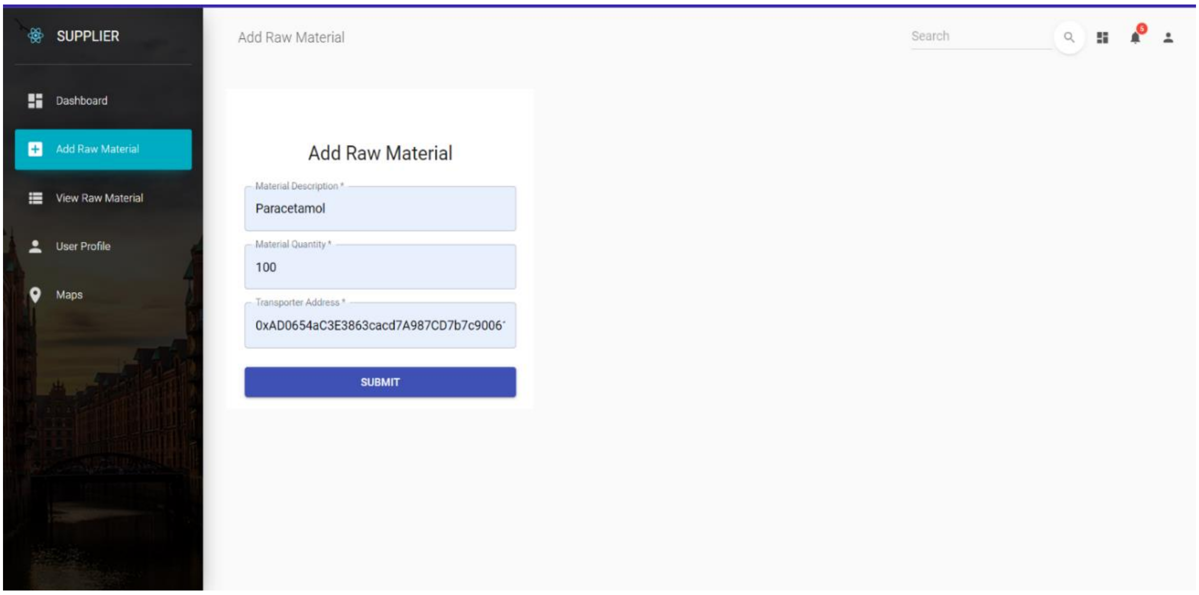
Contract	Gas Cost	Actual Cost (Ether)
Supply Chain contract	5055356	0.10110712 ETH
Raw Material contract	1015651	0.00142702 ETH
Medicine contract	1405550	0.0023604 ETH
Transaction contract	574042	0.0012762 ETH

5.4] BLOCKS SHOWN IN GANACHE UI

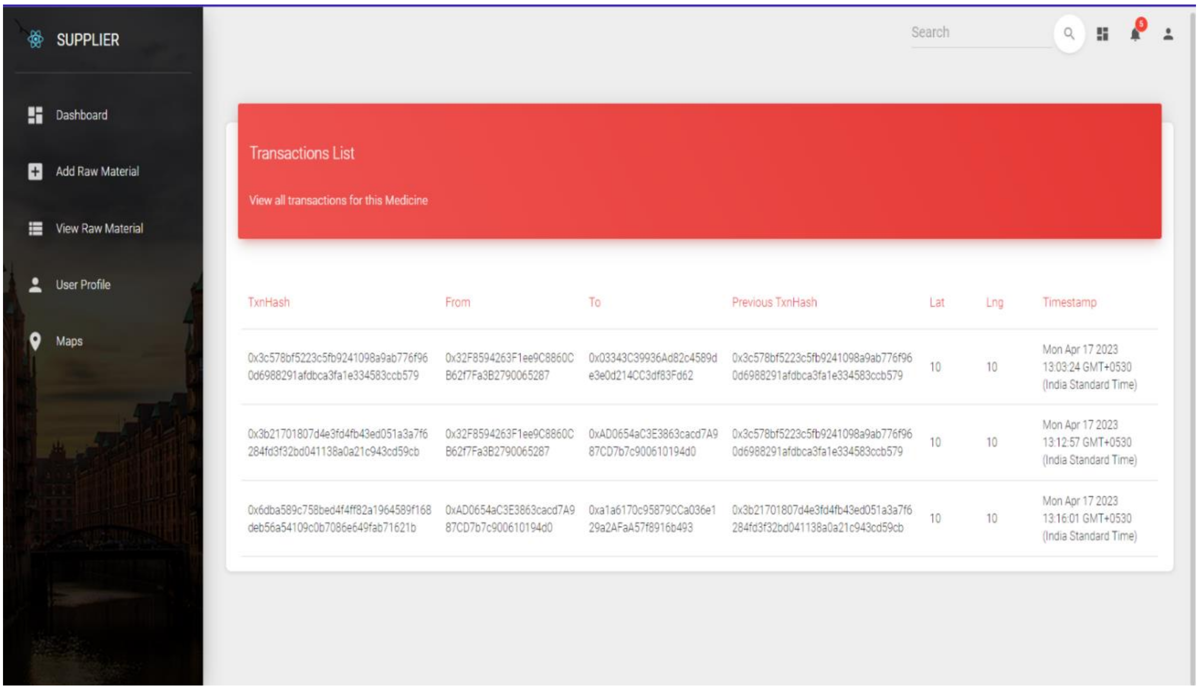


The contracts are deployed on a local blockchain provided by Ganache [16] which is part of the Truffle suite. The front-end (client) app is connected to the blockchain using Web3.js.

6] RESULTS



The Manufacturer entity can then request raw material by choosing the raw material he is interested in buying. Once he clicks the "Submit" button, the event request-response mechanism starts between the Manufacturer (Buyer) and Supplier (Seller). Once the raw material buyer is confirmed, the Raw Material contract is updated with the new buyer's address. The Transporter can then pick up the product, and the supplier hands the package to the Transporter, and a new transaction is then recorded in the Transaction contract of the raw material. When the Manufacturer entity receives the raw material, he verifies the signature associated with the transaction and then creates a new transaction in the Transaction contract. Thus, any further entity can view the transaction contract's records and verify the origin of the product, as shown in Fig. 8. The supplier can also view that the product reached the manufacturer by viewing the status, which updates in real-time on the Raw Material details page. The same response mechanism is used to transfer the products between different entities throughout the chain.



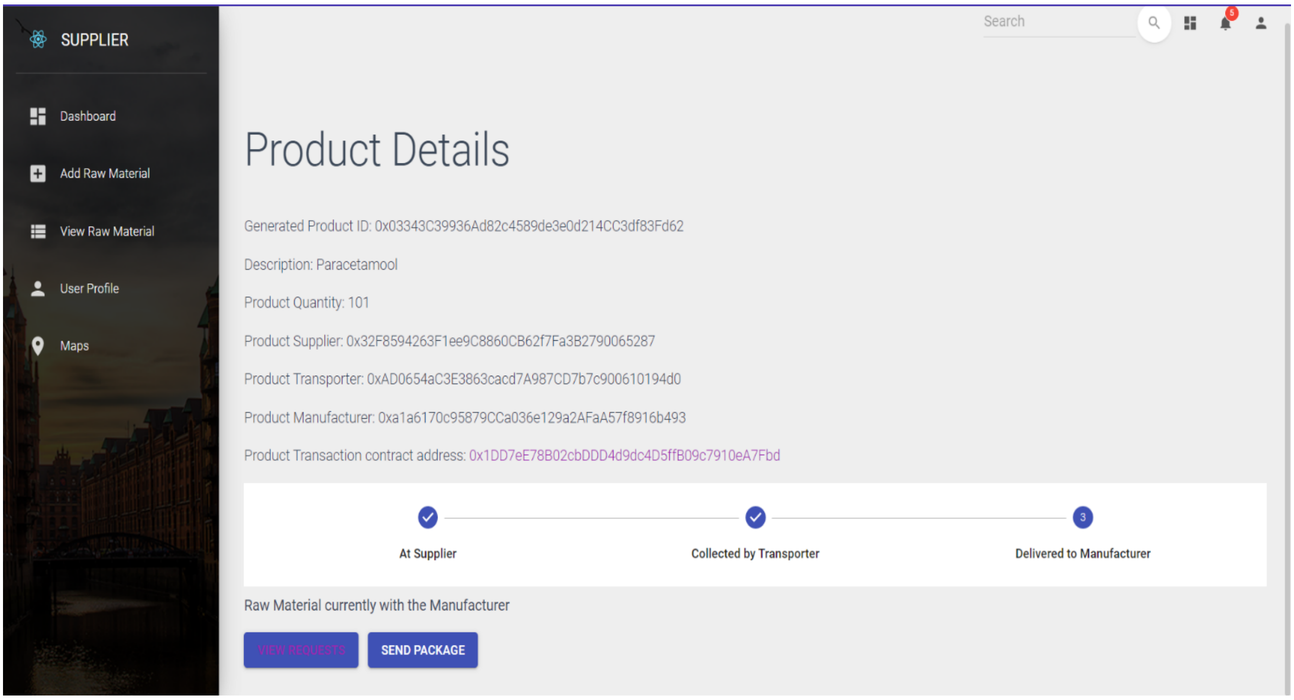


Fig. – Raw Material details page.

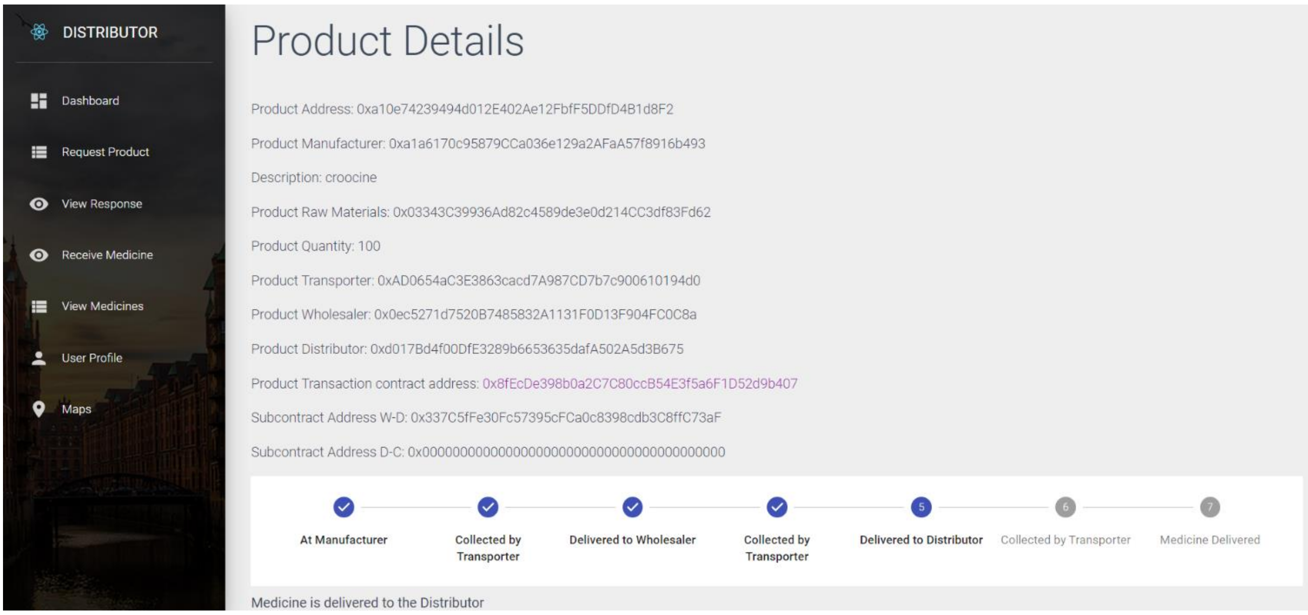
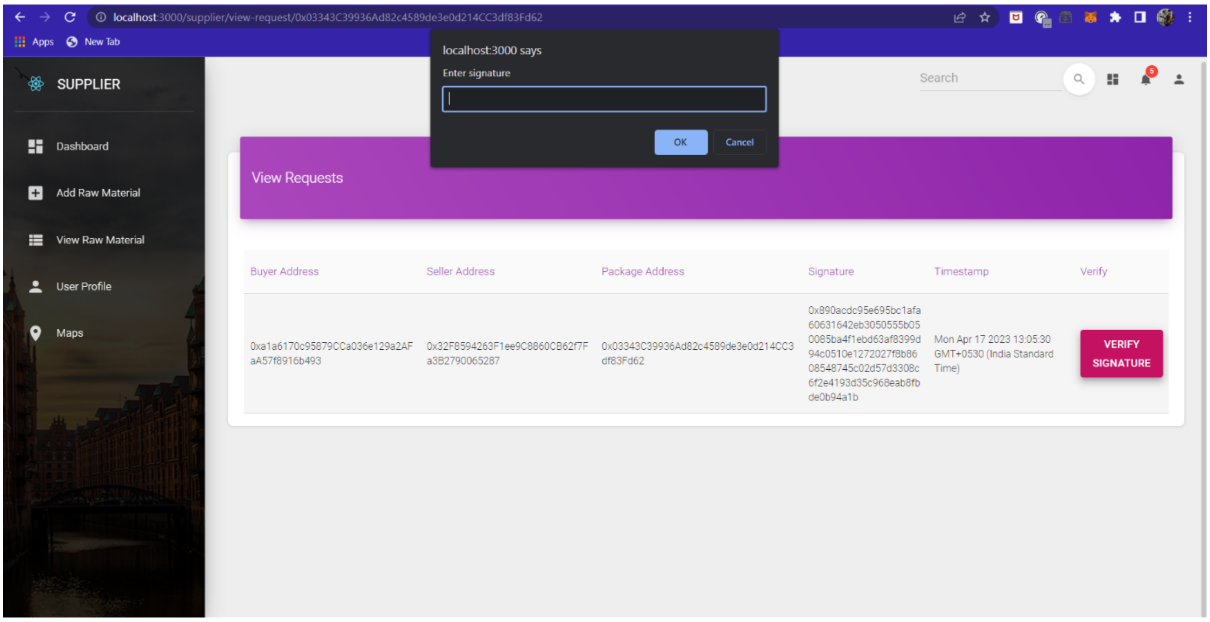


Fig. – Distrubutor page.

SIGNATURE GENERATION USING HASH METHOD.



7] CONCLUSION AND FUTURE SCOPE.

The report proposes a smart anti-counterfeit drug supply chain system based on blockchain technology and artificial intelligence. By using smart contracts and product registration and transferring, all product transferring records are permanently registered in the unchangeable ledger. The collaboration of smart contracts allows Tracking of the products. Consumers can also participate in the process of maintaining information flows. The proposed system has prominent decentralized characteristics, which significantly reduces the possibility of privately tampering with data.

Furthermore, an event request-response process was created to verify the identity of all parties and the signature found in the event in order to decide if the event is authentic. All events can be recorded and stored in the blockchain as a log, which can be viewed in real-time.

Finally, a decentralized application (DApp) was built based on the Truffle framework, deploy the smart contract, test the contract code through a local blockchain provided by Ganache, and implement a decentralized web app interaction interface based on the prototype. The system is characterized by data accessibility, tamper-proofing, and resistance to man-in-the-middle attacks.

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