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Blockchain based drug supply chain for decentralized network

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ABSTRACT

The concept of supply and demand drives the scales of various markets in today's world. When it comes to producing a quality product, the right kind of steps need to be taken to ensure that its quality can be supplemented with the process of its making. A supply chain is a business process that delineates the creation of a product. One such supply chain is the drug supply chain, focusing on the manufacturing and distribution of drugs. It is implied that there is an immense importance of traceability in the drug supply chain to ensure transparency amongst various actors and ultimately the end user. Improving on this crucial parameter allows drug supply chains to be carefully monitored and adhere to the various compliances from governing bodies. This work aim is to provide organizations with solutions that allow them to ameliorate the supply chain management. Using the blockchain technology, various transactions recorded in the supply chain can be checked against providing strong traceability and secure record-keeping. The positives that are provided by the blockchain transform the supply chain to a much more efficient and improved operation, impacting various facets of the process for the better.

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1. INTRODUCTION

Supply chain in the healthcare is a group of number of self-made units. These units are in the form of crude material suppliers, manufacturers, distributers, medical stores and patients. Due to the complexity involved in the entire chain of supply chain there are chances to produce wrong information throughout the process [1]–[3]. Also, the system may not be transparent and may not have original/complete data. Due to such incomplete information the drugs produced can't be original and effective. The duplicate drugs can have adverse impact on human health as well as there is a big loss of revenue of health care industry [4]–[6]. Due to incomplete information, centrally controlled data, and competition between multiple stakeholders tracking of material is very difficult in the supply chain management [7], [8]. Hence the entire process affects badly the supply chain which may lead to drug misplacement, break down the whole process [9]. Ultimately it leads to it leads to breakdown of entire management of supply chain. Hence this paper presents an Ethereum based blockchain approach using smart contracts and decentralization of data in supply chain for easy tracking of product of healthcare supply chain.

Supply chains are extremely important as they have a large-scale impact across various industries and global markets [10], [11]. Many supply chain-oriented businesses admit to not having a concrete methodology to manage it. The most impactful and sensitive supply chain where mistakes could be lethal is the drug supply chain. The primary need for drug traceability arises due to the complicated structure of a healthcare supply chain [12], [13]. Blockchain based approach could potentially solve complex supply chain issues of healthcare industry. The importance of drug traceability (track and trace) is highly needed and forced by several countries across the world [14], [15]. Drug traceability has become an integral part of the healthcare supply chain due to its important factors including authenticity, track and trace [16].

To address challenge of traceability and tracking efforts have been made by multiple authors so far. This paper presents a work which uses blockchain technology for drug supply chain management. The main objectives of the proposed system is:

i). To provide solution for drug supply chain management system which includes security, traceability, immutability, and accessibility using blockchain technology.
ii). To create and elaborate supply chains including various entities and assign respective roles.
iii). To address the issue of transparency and authenticity for stakeholders.
iv). To eliminate the need of intermediaries and keep track of transactions in an immutable ledger.
v). To create smart contracts to handle various transactions.
vi). To streamline transactional workflow for every entity in the supply chain using decentralized blockchain infrastructure.
vii). To improve traceability and operational efficiency by presenting the consumers with real, verifiable and immutable data.

The ideation of the proposed system focusses to aid pharmaceutical companies in setting up and managing their drug supply chains by using ideals of the blockchain technology. The system aims to solve discrepancies and streamline communication between various actors in the supply chain as well as allow companies to keep a track of product history through various phases of the supply chain [1], [2]. The system aims at minimize the losses of transactions and resources incurred due to the mismanagement of supply chains by allowing pharmaceutical companies to create, track and streamline their respective product chains [5], [6].

The basic concept of blockchain technology is similar to linked list data structure. Blockchain is a shared network where each node keeps local copy of all the blocks. Blockchain technology have feature of self-cryptography useful for transaction and public availability of distributed and centralized ledgers [17], [18]. The chains of blocks are connected via cryptographic constructs (hashes) are difficult to tamper the information. The records created are immutable and maintain integrity of the data stored on the ledger [19], [20].

Apart from being a blockchain oriented application, the project's domain becomes multi-faceted. It is aimed at assisting medical organizations and pharma businesses set up business-oriented supply chains [21]–[23]. This allows us to focus on both the healthcare and supply chain industries and draw inspiration from them. The use of blockchain allows a secure ledger to record all transactions of goods and materials in the chain [24]–[26]. The paper is organized in the four sections. The first section is introduction of the work, second section is methodology, third section is of result and discussion and last section is the conclusion of the work. Each of the sections is explained in details in the subsequent part of the paper.

2. METHOD

2.1. Literature review

The authors performed a rigorous literature review. A comprehensive study of literature indicates all the possible techniques and solutions proposed to address the drug traceability and drug duplicity issue. This section discusses various approaches used by the various authors in the literature.

Bhalerao *et al.* [27] presented a case wherein a simpler implementation is prescribed to streamline supply chains and allow for more transparency. It focuses on the more specific case of maintaining the temperature of a vulnerable material substance and thus develops its case around this particular case study. Although it presents a sufficiently good case to represent the usage of blockchain in its use case, it fails to bring up the true nature of blockchain's advantage of using it in the space of supply chain. It doesn't reveal itself fully enough to showcase the actual implementation of the application and only provides a rough idea of what the actual software's architecture is.

Wang *et al.* [28] examined the potential disruptive impact of blockchain technology in the supply chain industry. Upon careful analysis, it is inferred that enterprises and businesses prefer the technology on a permissioned network to ensure privacy, security, and access control. Consequently, the owner or enterprise retains centralized control. One particular area where blockchain offers significant value is in enhancing product visibility and traceability. However, there are certain technological hurdles associated with the implementation of this technology. One major challenge is the risk of a hacking attempt aimed at gaining control of the consensus validation by compromising more than 50% of the network. This threat poses a greater danger to permissioned networks compared to permission less networks. Additionally, latency and transactions per second pose another obstacle in utilizing blockchain effectively. Furthermore, the authors delve into the introduction and integration of the internet of things (IoT) within the realm of blockchain technology. This integration enables the generation of data through IoT devices, which can subsequently be leveraged for business purposes.

Chang and Chen [29] investigated the current state, potential uses, and future prospects of blockchain technology in supply chain management. The study involves a comprehensive review of existing literature on blockchain-based supply chain research to gain insights into its development and to identify the advantages, challenges, and issues in this domain. The analysis examines 106 review articles, providing an overview of how blockchain and smart contracts are applied in managing supply chains across various industries. The study highlights four key areas for future focus: traceability and transparency, stakeholder collaboration, supply chain integration and digitalization, and standard frameworks on blockchain-based platforms. The traditional supply chain faces challenges related to intermediaries, trust, and performance. Blockchain has the potential to revolutionize supply chain operations by enhancing performance, enabling distributed governance, and automating processes. It also points out the need for further research in technical adoption, integration of blockchain into supply chains, and the social impacts of these developments.

Shah *et al.* [30] explored the conceptualization and practical implementation of a streamlined process for tracking products within the supply chain, minimizing the need for manual intervention. The proposed approach suggests that this objective can be effectively achieved by incorporating radio frequency identification (RFID) technology, which provides real-time data. By utilizing RFIDs, each product within the supply chain is assigned a unique identifier that can be automatically detected and captured by RFID readers. This technology enables seamless tracking and monitoring of products as they move through various stages of the supply chain, such as production, warehousing, transportation, and delivery. The implementation of RFIDs in the supply chain reduces the need for manual data entry and minimizes the chances of human error. Instead of relying on labor-intensive processes, such as manual scanning or paperwork, RFIDs enable automatic and efficient data capture.

Ferdous *et al.* [31] examined various consensus algorithms, namely proof of work (PoW), proof of stake (PoS), and proof of elapsed time (PoET) with respect to their ability to validate transactions without relying on a third-party intermediary. The authors highlighted the energy-intensive nature and vulnerability to attacks of PoW and PoS, while also acknowledging their high scalability. Conversely, PoET is emphasized as an energy-efficient alternative. In addition, the work provides a concise overview of the hyperledger project, initiated by the Linux foundation, which specifically addresses the requirements of enterprises in the context of permissioned blockchains. The authors of the paper conducted a comprehensive analysis of annual data to examine the preference for different consensus algorithms. Interestingly, their findings revealed that a significant number of users still heavily rely on the PoW algorithm despite its drawbacks.

Hugos [32] described a collection of works and papers by various authors, that enumerates various issues and aspects of a supply chain and provides operational and design-wise management of the same. It talks about the essence of supply chains and what their designs should be like, covering a wide array of topics like supply chain operations, new technologies that can be incorporated, metrics for measuring performance of the chain and elucidates many such issues and parameters that revolve around supply chains. This paper was primarily used to get a contextual understanding of the industry that our proposed idea was going to impact. Therefore, this massive knowledge bank includes various instances of modern abilities of supply chains and its impacts on global variables like the economy. It also delves into certain commercial aspects of supply chain management wherein it attempts to find scope of supply chains in fresh “modern-day” economies and opportunities. Although it is quite comprehensive, it is not a “quick” guide, its volume in the knowledge it tries to deliver is at times too much for someone who wants to get an overview on the topic. Needless to say, this refined collection of texts allowed us to think from perspectives that are relevant to the management of supply chains.

Cui and Idota [33] addressed the crucial challenge of enhancing supply chain resilience. Through a comprehensive analysis of the existing literature, the authors emphasize the significance of effective information sharing in mitigating risks and improving resilience. They propose a decentralized information sharing mechanism as a solution, offering a novel approach to address the challenges in supply chain management. The paper showcases the benefits of their proposed mechanism through simulations or case studies, highlighting its effectiveness in enhancing operational efficiency and resilience. Although their case is strong, it fails to make any sound implementation of the paper’s major idea, therefore, the idea dies at a hypothesis state and does not attach itself to any solid result.

Zhang *et al.* [34] described blockchain technologies, like the bitcoin system, operate as decentralized networks where each participant maintains a record of all transactions in order to independently verify new transactions. However, this decentralized approach results in a rapid growth of the blockchain transaction database's size. As a consequence, nodes must continuously expand their memory capacity to sustain system operations, especially in the context of the big data era, where increasing network traffic accelerates the transaction growth rate. This research addresses the issue of blockchain transaction database storage by proposing techniques for efficient storage management. The technique utilizes a recognition method based on the least recently used (LRU) algorithm to categorize blockchain transaction databases into hot zones and cold zones. Through the relocation of unspent transaction outputs from the in-memory transaction databases, the proposed approach successfully attains storage efficiency. The paper includes theoretical analysis to demonstrate the effectiveness of the optimization method, and extensive experiments confirm that the proposed solution outperforms the current mechanisms used for blockchain transaction databases.

Juričić *et al.* [35] offered unique perspectives on blockchain technology and suggest a class of computational problems for which no efficient solution algorithm has been found as a viable replacement for the current consensus algorithm. In this research, a wide variety of proposed alternatives is considered, including distributed volunteering for scientific purposes and different consensus algorithms that can be used in cryptocurrencies. By leveraging the unique properties of unsolved computational problems, diverse domains such as science, biology, medicine, and finance can benefit from effective problem-solving capabilities. Additionally, this approach has the potential to enhance business processes, optimize markets, payments, and supply chains, while simultaneously reducing environmental costs. The paper emphasizes the ongoing development and adoption of alternative mechanisms to replace less efficient blockchain algorithms.

Khan *et al.* [36] examined the influence of blockchain technology on supply chains, carefully evaluating the advantages and obstacles associated with its implementation. It sheds light on the prevalent challenges faced by supply chains, such as limited visibility and the need for sustainable processes. Through a thorough analysis, the study demonstrates the crucial role of blockchain technology in enhancing the sustainability of supply chains. However, it also emphasizes that to fully leverage the benefits of blockchain, it is imperative to have unwavering commitment from top management and the implementation of efficient organizational policies. Ultimately, the work concludes by emphasizing the capability of blockchain to enable real-time product tracking, leading to substantial reductions in supply chain costs.

The literature reviewed is summarized in a Table 1, the attributes of the table contains title of the paper surveyed, authors, remarks. The remarks are in the form of key features of the paper. The key features are mainly in the form of advantages, disadvantages, technical aspects used in the paper. The summary of literature survey is used to formalize the problem statement of the proposed work.

2.2. Working

The Figure 1 illustrates a high-level workflow of the proposed pharmaceutical supply chain redefined using ideals of blockchain. The system deals with linking various actors and entities in the supply chain over a block chain network using smart contracts. The Pharmaceutical Company who wishes to track the immutable records of their supply chain registers on the application and registers its respective actors during the process. A smart contract is developed for each actor in the chain. The records are updated by each actor at every step of the chain. The smart contracts mentioned in the Figure 1 are integrated into a predefined supply chain smart contract. The data and records in the same can be accessed by the application through an application programming interface (API) and are thus rendered on the graphic user interface (GUI) of the application.

Figure 2 explains the high-level workflow of the application. The Pharmaceutical Company registers on the application by entering necessary information or logging into their accounts if already created. The application sets up the supply chain once the pharmaceutical organization creates its actors and entities. The supply chain defines these actors/entities which interact with the smart contracts using the metamask wallets. The status of the products and the records are updated into the supply chain which can be then queried by any authorized actors or the Pharmaceutical Company.

The Figure 3 illustrates the system architecture in the form of structural division of the pharmaceutical supply chain web application into three components: frontend, backend and smart contracts that encompass all the functionalities of the application. The frontend of the web application consists primarily the user interface which has been developed using frameworks like ReactJS for structuring the components and Tailwind cascading style sheets (CSS) for styling the components respectively. The user interface is further divided into several components such as pages for login and registration purposes, landing page, there is a verification functionality that validates the authentication of the pharmaceutical company signing up. The frontend also consists of a real-time dashboard that displays all the events that have been recorded and tracked by the smart contracts such as actor addition, deliverable and product generation, product shipping, transformation and ownership transfer functions. The dashboard in the pharmaceutical supply chain plays a crucial role in providing a visual representation of all the events logged by the application. The dashboard enables actors to view and monitor the different transactions and activities happening in the supply chain. The dashboard provides real-time data and insights on the status of products, their location, and other critical information that can help identify potential issues and improve supply chain efficiency.

Table 1. Summary of literature survey

Sr. No.	Title of paper	Authors	Remarks
1	Supply chain management using blockchain	Bhalerao *et al.* [27]	Paper emphasizes on the importance of proper temperature maintenance of vulnerable materials; it contains no implementation details with respect to the blockchain technology.
2	Understanding blockchain technology for future supply chains: a systematic literature review and research agenda	Wang *et al.* [28]	Paper analyzed a general preference of business enterprises w.r.t the blockchain network used in their supply chain operations. With a concept of integration of IoT into the system, the paper delves into the potential improvement of the supply chain operations in the industry.
3	When blockchain meets supply chain: a systematic literature review on current development and potential application	Chang and Chen [29]	This study provides valuable insights into the current state and future potential of blockchain in supply chain management, addressing critical issues and highlighting the benefits and challenges associated with its adoption.
4	Blockchain-based pharmaceutical drug supply chain management system	Shah *et al.* [30]	Paper presents an innovative approach for product tracking in the supply chain by integrating RFID technology, offering real-time data and streamlining the process while minimizing human intervention and potential errors.
5	Blockchain consensus algorithms: a survey	Ferdous *et al.* [31]	Paper thoroughly examines different consensus algorithms, highlighting their strengths and weaknesses. It also provides valuable insights into the Hyperledger project and presents intriguing findings on the continued usage of the energy-intensive PoW algorithm in spite of its limitations.
6	Essentials of supply chain management	Hugos [32]	Paper provides a comprehensive collection of works and papers on various aspects of supply chain management, offering valuable insights and perspectives for understanding the industry and its impact on global variables.
7	Improving supply chain resilience with establishing a decentralized information sharing mechanism	Cui and Idota [33]	The paper presents a promising concept of decentralized information sharing for improving supply chain resilience, but lacks concrete implementation and empirical results to support its hypothesis.
8	A storage optimization scheme for blockchain transaction databases	Zhang *et al.* [34]	The paper addresses the challenge of growing blockchain transaction databases and proposes a storage optimization scheme based on expiration recognition methods, showing improved performance compared to the current mechanisms.
9	Optimizing the resource consumption of blockchain technology in business systems	Juričić *et al.* [35]	The research explores the potential of incorporating NP-complete problems as an alternative consensus algorithm in blockchain technology, highlighting their applicability in various domains and potential for enhancing efficiency and usability.
10	Blockchain technologies as enablers of supply chain mapping for sustainable supply chains	Khan *et al.* [36]	This research paper provides a comprehensive evaluation of the impact of blockchain technology on supply chains, highlighting its potential in improving sustainability and reducing costs, while emphasizing the need for management commitment and efficient organizational policies for successful implementation.

The backend of the pharmaceutical supply chain is based on node.js architecture and consists of several components that perform different functions. The user-related create, read, update and delete (CRUD) operations enable the creation, retrieval, updating, and deletion of actor-related information in the database. This component provides the necessary functionality for registering and managing actor accounts in the system. The email verification API enables the verification of user email addresses to ensure the authenticity of user accounts. When a new user registers and adds actors in the supply chain, the API sends a verification email containing a unique link that the user must click to verify their email address and activate their account. The mailing functions component provides the necessary functionality for inviting users to join the supply chain network. This component sends out email invitations containing a link to the registration page, allowing new users to join the network. The express routes component defines the endpoints for the various APIs used in the system. This component provides a standardized way for clients to interact with the backend system and perform necessary actions, such as creating new products, transforming and shipping products, updating supply chain information, and retrieving data.

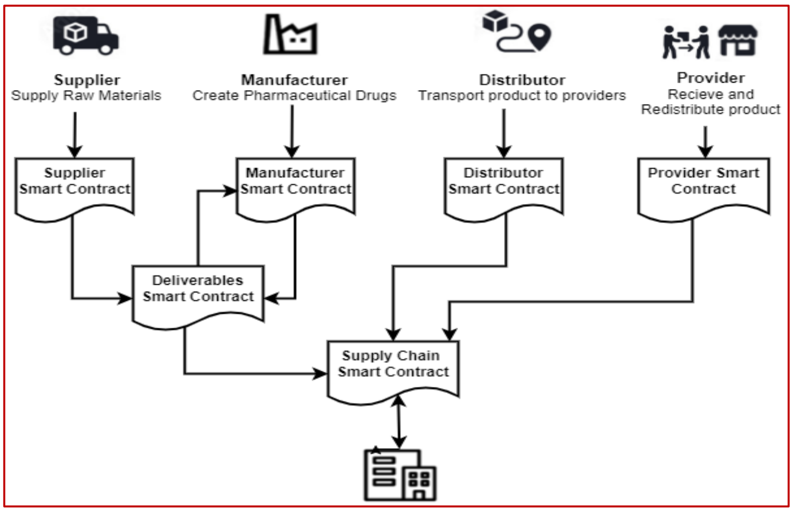

Figure 1. System workflow

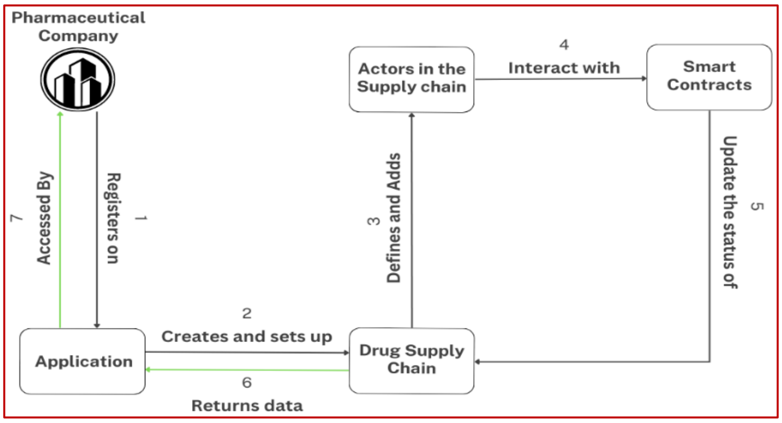

Figure 2. High level workflow

The blockchain components of the pharmaceutical supply chain web application consist of several files and contracts that work together to ensure the integrity and security of the supply chain data. The smart contract application binary interface (ABI) file defines the interface for the smart contracts used in the system. The compile script is used to compile the smart contracts written in solidity. The deploy script is used to deploy the compiled contracts to the Ethereum blockchain. The web3.js specification is a JavaScript library that allows interaction with the Ethereum blockchain. The Mumbai/Goerli testnet is a testing environment used to test the smart contracts and the system. The supply chain factory contract is used to create new supply chain contracts. The supply chain contract contains the necessary functions and events to manage the supply chain data. It also manages the creation and tracking of various actors in the supply chain and provides the necessary functionality to perform the different actions, such as creating deliverables, shipping products, and transforming products.

In this system, the frontend plays a crucial role in fetching and processing information from blockchain transaction logs to construct a comprehensive timeline. The timeline comprises essential details such as date, time, location, and the responsible entity for each event recorded in the blockchain. The events are categorized, and based on these categories, the frontend intelligently renders the timeline for the user. The level of detail presented on the frontend depends on the user's authorization status within the blockchain network. If the user is an authorized actor, such as a participant within the blockchain network, they gain access to a more exhaustive and intricate timeline view. On the other hand, if the user is a customer without direct involvement in the blockchain, they are presented with a simplified and abstracted version of the timeline tailored to their specific requirements. To facilitate the customer's access to this timeline, a QR code is generated using the log details by the blockchain entity, enabling convenient and secure retrieval of the relevant information. By leveraging the frontend's capabilities, users can interact with the blockchain data efficiently and effortlessly. The frontend's ability to extract, structure, and present essential information from the complex blockchain logs enhances the user experience, making it easier for both authorized actors and customers to access pertinent details. The authorization-based differentiation of timeline views ensures that sensitive information remains secure and accessible only to relevant parties, safeguarding the integrity and privacy of the blockchain network. With the convenience of QR code scanning, customers can effortlessly access an abstracted version of the timeline, tailored to their specific needs, without the need for technical expertise or direct involvement in the blockchain.

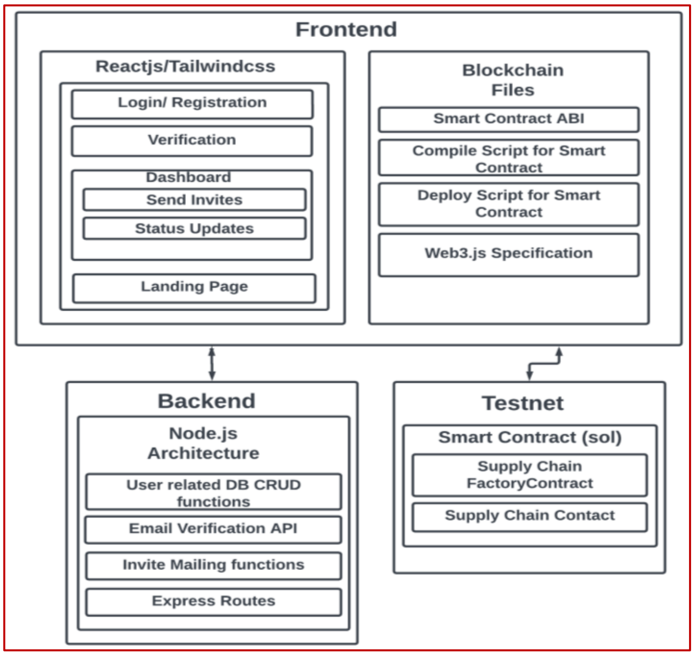

Figure 3. System architecture

Ethereum's cardinal feature to developers was its ability to allow self-executing scripts to be "hosted" on the blockchain, from where they could be interacted with by the other accounts of the blockchain and perform transactions or their proposed tasks. This opened up the accessibility of blockchains to a larger bracket and allowed developers to make better use of its unique infrastructure. Smart contracts allow an account on the blockchain to interact with itself and provide other value propositions to the user. The understanding of the word "contract" to a layman would be an apt description of how these scripts work. The contract's functions can be externally triggered by any account transacting on the blockchain, it is imperative that certain conditions can be written into the contract which can allow itself to execute separate functions depending upon the payload of the transaction. As is innate to the characteristic of a transaction, all "calls" to the smart contract are traceable in the realm of the blockchain. Due to the nature of the project's objective and the desired result, it was agreed upon that smart contracts would be the ideal hallmark of blockchains that could be experimented and exploited to achieve the goal of the application. Hence three smart contracts were designed that could provide a well-connected instrument of communication and preserve the supply chain's state behind a cryptographically bound system.

The logic of the smart contracts written in solidity was initially compiled using the solidity compiler. Web3 library was used to deploy the compiled smart contracts to local Ethereum blockchain. A web3 instance was created and connected to the local Ethereum blockchain. The contracts to be deployed were obtained from the 'compiledDeploySupplyChain.json' file, which should contain the ABI and bytecode of the contract. The deploy function was defined which is an asynchronous function that will handle the deployment of the smart contract. The web3.eth.getAccounts() is called wherever required in the react.js code to get a list of available Ethereum accounts. These accounts are necessary to deploy the contract. The ABI also allows to call other methods implemented in the smart contracts as and when required in the react code written for frontend. Error handling was used to handle any errors that may occur during the contract deployment. If there is an error, it will be logged to the console otherwise if the deployment is successful, the deployed contract's address will be available for future use.

3. RESULTS AND DISCUSSION

3.1. QR code

The blockchain-based drug supply chain project implementation involved attaching a unique QR code to each drug pack, allowing customers to scan the code and access the tracking logs specific to that drug. QR code that contains encrypted information related to the drug's origin, manufacturing details, and supply chain journey. The sample QR code is shown in Figure 4.

Figure 4. QR code attached to drug packets

3.2. Tracking logs

The tracking logs stored on the blockchain prove to be highly effective in ensuring the traceability of drugs throughout the supply chain. Each time a drug pack moved from one entity to another, the relevant information, such as date, time, location, and responsible party, is recorded on the blockchain. This enables stakeholders, including suppliers, manufacturers, distributors, and end users, to access and verify the complete journey of the drug. Figure 5 shows web interface of the tracking system.

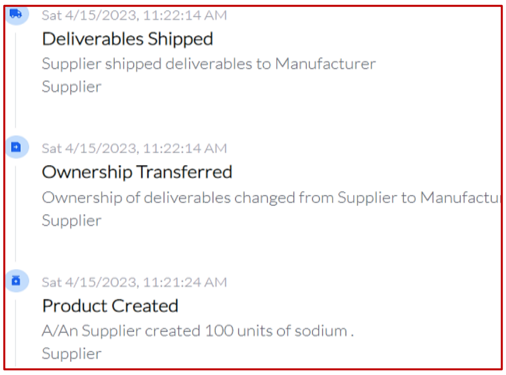

Figure 5. Web interface on scanning the QR code

3.3. Supply chain transparency

By leveraging blockchain technology, the project significantly improves transparency within the drug supply chain. The tracking logs attached to the QR codes provided an immutable and auditable record of each drug's movement, ensuring accountability and reducing the risk of counterfeit or compromised products. This increases transparency contributed to building trust among stakeholders and strengthening the overall integrity of the supply chain.

3.4. Security and data integrity

The blockchain-based system demonstrates robust security measures and ensures data integrity throughout the supply chain. The use of decentralized ledger technology eliminates the need for a central authority, reducing the risk of data tampering or manipulation. The security is maintained using encryption and integrity with the help of immutable blocks of blockchain.

4. CONCLUSION

The proposed application caters to the creation of elaborate supply chains, ensures transparency and authenticity, eliminates the need for intermediaries, and keeps track of all transactions, processes and events in an immutable ledger which can greatly benefit the pharmaceutical industry. Also, it creates, track, streamline their product chains and minimize the losses incurred due to mismanagement and enable a more efficient and reliable supply chain. This application can lead to increased trust and confidence in the pharmaceutical industry, ultimately benefiting all stakeholders involved. Furthermore, the use of blockchain technology in the pharmaceutical industry can also improve the safety and security of the supply chain by reducing the risk of counterfeit drugs and ensuring compliance with regulatory standards. The immutable nature of the blockchain ledger allows for easy tracing and auditing of the entire supply chain, from the production of raw materials to the distribution of finished products. Moreover, the decentralized nature of blockchain ensures that there is no single point of failure in the system, making it more resilient to cyber-attacks and ensuring the continuity of operations even in the face of disruptive events. The adoption of blockchain technology in the pharmaceutical industry can revolutionize the supply chain management process by enhancing transparency, security, and efficiency. This can translate into significant cost savings, better compliance, and ultimately, improved patient outcomes.

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