

# Blockchain-based Vaccine Distribution Scheme for Future Pandemics

A Aadhitya<sup>1</sup>, S Manoj<sup>2</sup>, N Shankar<sup>3</sup> and M.R Sumalatha<sup>4</sup>

<sup>1-4</sup>Department of Information Technology, Anna University - MIT Campus, Chennai, India

Email: aadhitya864@gmail.com, manoj.selvam312@gmail.com, shankarsar9942@gmail.com, sumalatha@annauniv.edu

**Abstract**—The transportation of medicines and vaccines is a crucial aspect of healthcare, but ensuring their integrity during transit can be difficult. This is particularly true for vaccines that require cold-chain preservation to maintain potency and stability. Regulations and guidelines add further complexity, resulting in a need for a reliable, transparent, and secure supply chain. Blockchain-based solutions, particularly those utilizing smart contracts, can provide such a system, allowing real-time monitoring of vaccine movement and facilitating collaboration between governments and healthcare organizations. By registering, tracking, and verifying vaccine supply details, decentralized apps can improve the success of the cold-chain process while ensuring security and transparency in the vaccine supply chain.

**Index Terms**— Blockchain, Smart Contracts, Supply Chain, Ethereum.

## I. INTRODUCTION

A vaccine supply chain is a system that entails each step needed to move a vaccine from its manufacturing location to the location where it will be administered. Every step of the supply chain needs to be planned to guarantee the vaccine's quality, effectiveness, and safety. On the other hand, flaws might appear at any stage of the production process and lead to a poor or even hazardous product. The most crucial component of the vaccine supply chain is the cold chain, a system of refrigerated transport and storage used to maintain the vaccine at a constant, safe temperature. If the cold chain is not adequately maintained, the vaccine may deteriorate and lose its effectiveness.

A worldwide health emergency or an unanticipated rise in demand for a single vaccination can both result in vaccine shortages. For individuals who need the vaccine, this might mean long wait times and rationing. The vaccine supply chain is generally dependable and guarantees that many people who need a vaccine may acquire one, notwithstanding the likelihood of issues. Unfortunately, the current situation has several problems that make the vaccination supply chain unreliable.

Blockchain can be used in vaccine supply chain management to address these issues. The use of blockchain has the potential to improve vaccine traceability and increase transparency in the distribution of these life-saving products. Authorities would be able to identify and correct any issues with the distribution of these products if they could track the movement of vaccines through the supply chain using blockchain more easily. Furthermore, the use of blockchain could help to ensure that all stakeholders in the vaccine supply chain have constant visibility into the product's status, thereby avoiding any delays or disruptions in the distribution of these critical products.

## II. RELATED WORKS

Antal et al., (2021) [1] proposed a blockchain-based system for transparent tracing of vaccines, registration, storage, delivery and side-effects reporting using smart contracts. The proposed method worked well but not implemented in a web app as the experiment is simulated. Kumar et al., (2021) [2] proposed a smart vaccine management system which would address the issue of vaccine expiration and counterfeiting. The management system leverages the usage of blockchain ADI model. The proposed system had a great scope in terms of usage in the public but the app is limited to the application of blockchain and IoT devices. Ng et al., (2021) [3] made a review about usage of blockchain in healthcare industry such as Contact tracing, Genomics, Supply chain management system, Telemedicine. Kashyap et al., (2022) [4] created a vaccine supply chain administration system using blockchain to address the issues in present supply chain system. The proposed work is done both in single as well as double blockchain and it is found that the double blockchain consumes more resources and is complicated, making it hard for users to implement. The experiment is done in testing environment. Kamenivskyy et al., (2022) [5] proposed a blockchain based supply chain network which would perform all the required tasks of the vaccine supply chain while protecting the data from intruders. The validation phase isn't complete and the authors denoted that as the limitation of the work. Bennacer et al., (2022) [6] used smart contracts to create a blockchain-based digital health passport on both on-chain and off-chain (IPFS based) storage. The proposed work satisfied the problem issue, but the testing was done in Remix IDE VM environment. Khanna et al., (2022) [7] proposed BEVDS: a blockchain model with multi-authentication system for vaccines. UIDAI database is used along with Blockchain to enhance the security of multi-authentication system which would avoid auth-based identity attacks. However, practical implementation isn't made yet. Cao et al., (2022) [8] proposed a blockchain-based passport system which works on double blockchain system (public blockchain and consortium blockchain) along with IoT technology. The proposed work ensured transparency, security and also solved some of the issues in the distribution system. Saidi et al., (2022) [9] described about the challenges present in current vaccine supply chain system and blockchain can be used to solve those issues. Loss et al., (2022) [10] proposed a blockchain adapter for FIWARE, an open-source middleware developed for smart city solutions (with support from European Union) to integrate with blockchain technology. The operations included vaccine chain management system. Though the authors proposed the blockchain adapter, they didn't test it and conveyed that they are still in development. Elangovan et al., (2021) [11] proposed a weight-based deduplication method for minimizing data replication in public cloud storage. The proposed method uses a weight function to determine the similarity of data blocks, and then uses this information to determine which blocks should be deduplicated. The authors evaluate the performance of their method using a dataset of real-world files and show that it is effective at reducing data replication and improving storage efficiency. Velmurugan et al., (2022) [12] proposed a supply chain financial risk management method that uses business intelligence. The authors propose a framework that integrates data from multiple sources and applies machine learning techniques to identify and analyse financial risks in the supply chain. The authors suggest that the proposed method can provide valuable insights for supply chain managers and help them make more informed decisions.

Villarreal et al., (2023) [13] conducted a survey on usage of blockchain technologies in the field of healthcare management systems. The authors' work focused on two main objectives, to explore the architectural mechanisms used in the system and validation of the smart contracts. Al-Sumaidae et al., (2023) [14] proposed blockchain technology as a governance data management system in healthcare. The authors used Hyperledger Fabric to improve the flow speed of information and solve the fragmentation problem between entities. Hyperledger Caliper is also used to evaluate the network performance. Karmakar et al., (2023) [15] proposed Chainsure, an Ethereum blockchain-based framework designed to solve the issues present in typical healthcare management systems. With the power of TOPSIS and smart contracts, the authors stated that ChainSure provides an automated, tamperproof, transparent, scalable system that will take care of all the major functional blocks in a medical insurance environment. The proposed method is found to outperform others in terms of service integrity, latency and cost.

## III. PROPOSED WORK

A vast and intricate global network of producers, suppliers, distributors, healthcare professionals, and patients make up the vaccination supply chain. The vaccination supply chain could become much more transparent and efficient thanks to blockchain technology. Blockchain is a distributed database that makes it possible to store data in a secure, open, and unchangeable manner. This makes it a great technique for monitoring the distribution

of vaccines. Blockchain may be used to trace the origin of vaccines, make sure they are handled with care throughout storage and delivery, and make sure the right people receive them. By offering a full and impenetrable record of all vaccine transactions, blockchain can also help increase transparency. This could increase confidence in the vaccination supply chain and lower the likelihood of fraud.

#### *A. Contracts*

The most crucial stage in developing a web3 app using ETH is the creation of smart contracts. Contracts are programs that are stored on a blockchain and are executed when certain criteria are met. They also serve as a unique certificate for every transaction (that is, operation) made by the user on the ETH. Contracts in ETH are written in Solidity. The execution steps for contracts are given as follows:

- To start a contract, first it must be drafted by the user or developer.
- While drafting a smart contract, the transaction fees must be considered while designing. If the program is more complex, then the transaction fees are high. (Transaction fee = Total gas used\*gas price)
- After drafting the contract, it must be compiled to make sure it is free of errors.
- After compilation, the contract is deployed to the ETH network via web3 wallet. If successful, the transaction will take place in seconds to hours depending on the traffic of the ETH network.
- Once the transaction is complete, the developer can start using the smart contract in live.

#### *B. Local Network*

Since the main ETH network is hard to implement in the project due to requirement of funds in the Ethereum, test networks could be implemented to simulate the working environment of ETH. By this way, the funds can be acquired for free via faucets provided by the test networks. In this project, Ganache EVM is used.

The features present in Ganache test network are as follows:

- Simulation of transactions is possible in Ganache
- No real funds are used in the process
- Easy to link with a web3 wallet
- Wallets are automatically populated with free ETH during startup
- Smart Contracts can be easily deployed in the network without Gas fees issues

#### *C. web3JS*

web3.js is a NodeJS library that allows one to interface with a local or distant Ethereum node using HTTP, IPC, or WebSocket. This library is useful in interacting with the ETH contract deployed once its Application Binary Interface (ABI) and address are known and also helps to perform operations like contract deployment, getting values from contract, sending data to contract and a lot more.

#### *D. Truffle*

Truffle is a development environment, testing framework and asset pipeline for Ethereum, aiming to make life as an Ethereum developer easier. It provides a suite of tools for developing smart contracts with Solidity and testing them in a sandboxed environment. It is also a command line tool that provides several commands for managing your Ethereum development workflow. These include commands for compiling your smart contracts, running tests, migrating your contracts to different networks and more.

#### *E. Metamask*

MetaMask is a digital wallet that allows you to store, send, and receive cryptocurrency. It also allows you to connect to decentralized applications (dApps) on the Ethereum network. This is used as it provides an interface for interacting with the smart contract deployed over the local network.

From the above components and libraries, the architecture and flow diagram are made. The flow diagram of the web app is shown in Fig. 1 and Fig. 2.

#### *F. Algorithm*

The algorithm of the proposed vaccine supply chain system along with the role description is given below:

1. Start
2. Initialize the smart contract on the Ethereum blockchain and describe the responsibilities of the contract's Manufacturers, Suppliers, and Users.
3. Make the user to login into the web app using the address present in the wallet
4. If the role is manufacturer, invoke a function in the smart contract to register the vaccines.

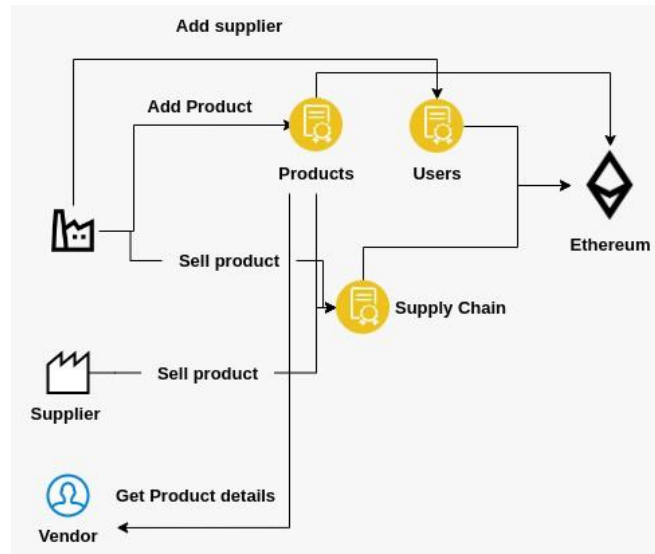


Figure 1. Architecture of the vaccine supply chain

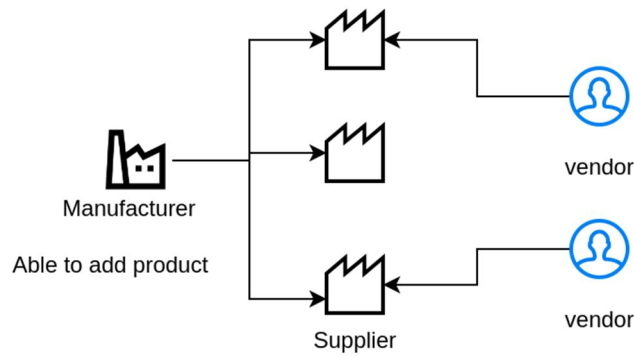


Figure 2. Flow diagram for Manufacturer and Supplier

5. If the role is Supplier, invoke a function in the smart contract to update the location and status of the vaccines.
6. If the role is user, invoke a function to request vaccines from the supply chain by calling a function in the smart contract and specifying the desired quantity and location.
7. End if user logs out

The pseudo code for the above algorithm is given in algorithm 1

---

**Algorithm 1** Vaccine Supply Chain System with different roles

---

```

if wallet  $\leftarrow$  NULL then
    ThrowException()
end if
startWebApp()
user  $\leftarrow$  walletAddress()
if user  $\leftarrow$  Manufacturer then
    session  $\leftarrow$  adminSession
    option  $\leftarrow$  input
    if option  $\leftarrow$  addUser then
        page  $\leftarrow$  addUser
        userDetails  $\leftarrow$  input storeUser()
    end if
    if option  $\leftarrow$  addProducts then

```

```

        page ← addProducts
        productDetails ← input storeProduct()
    end if
end if
if user ← Supplier then
    session ← normalSession
    option ← input
    if option ← addUser then
        page ← addUser
        userDetails ← input storeUser()
    end if
    if option ← TransferProduct then
        page ← ProductTransfer
        productDetails ← input
        targetUser ← input
        transferProduct(targetUser)
    end if
    if user ← User then
        session ← normalSession
        option ← input
        if option ← addUser then
            page ← addUser
            userDetails ← input storeUser()
        end if else
            throwException()
        end if
    end if
end if

```

---

#### IV. RESULTS

The proposed dApp is tested under Ganache EVM. The dApp performed well in terms of deployment and sending values. The transaction part took considerable amount of time as the validation work is present after each transaction operation such as addUser(), addProduct(). However, in overall, the web app performed well. In the project, 4 smart contracts are deployed in the network. They are as follows: Products, Users, Types, SupplyChain. The SupplyChain contract from the above list acts as the super class for the other 3 contracts.

The contracts worked normally only if the given scenarios are present:

- If the user has no balance in the ETH account, then the contract won't get deployed as some ETH is required to deploy even if the transaction fees made by contract is 0. So, the user must have some amount of ETH in the wallet.
- Correct wallet address has to be provided during login session else the web app would fail to work during operations.
- A super user has to be assigned during contract deployment. Only through the super user (manufacturer) the products can be added.

##### A. Debugging Contracts

After the contracts are deployed over the network, they are debugged to check if there are any issues in the contract. Any faults in the contract code might result in unintended effects like security flaws, money loss, or improper behavior, so it is crucial to debug a smart contract to make sure it works well and as intended. Debugging a contract can help developers find problems and errors in the code so they can correct them before publishing the contract to the blockchain. It also aids in ensuring that the contract operates as anticipated and complies with the conditions and guidelines specified in the contract design. In this case, the debugging is done with the help of Remix IDE. During the process, no issues were found in the compiler code and it is shown in Fig. 3. The results shows that the contracts are free of errors.

##### B. Load Testing

In order to assess a website's capacity to handle the anticipated workload, load testing a web app is a critical component of web development. A web app must be load tested in order to find performance bottlenecks, figure out the site's capacity, boost website dependability, and guarantee scalability. Load testing can assist identify

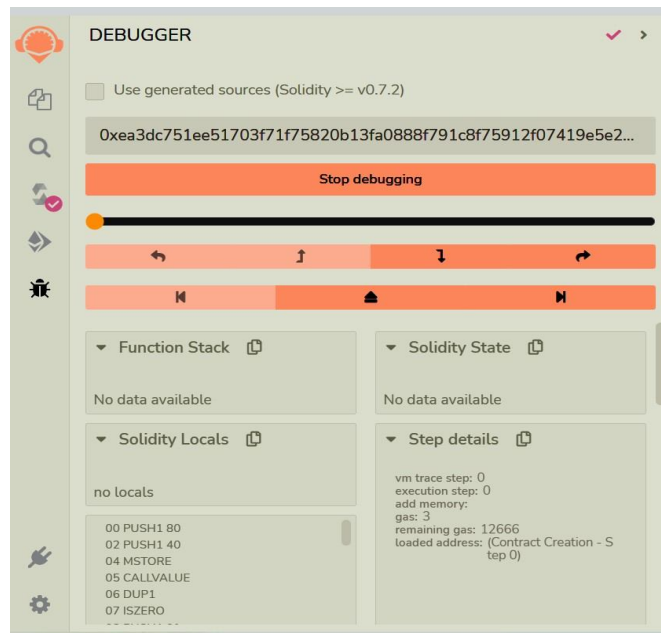


Figure 3. Debugging smart contracts using Remix IDE

problems like sluggish loading times or unresponsive pages by simulating high traffic, enabling developers to improve the functionality of the website. By spotting and resolving possible issues early on, this increases the stability of online apps. The dApp is made to test under a load of concurrent 10000 users using Locust, a Python package for load-testing websites. The website handled well with simulated high load of users and the results of the load test are shown in Fig. 4 and Fig. 5.



Figure 4. Total Requests Per Second made on the website using Locust

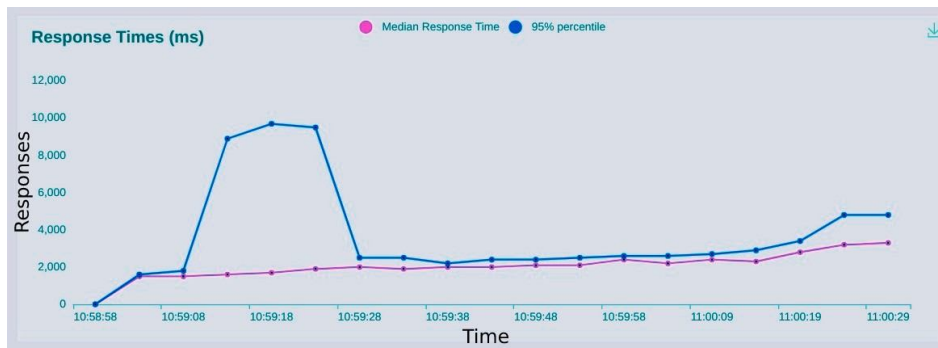


Figure 5. Performance of the website in terms of response time

### C. Smart Contract Performance

It is critical to evaluate a smart contract's performance in terms of execution speed because it has a direct bearing on both the user experience and the cost of carrying out the contract. The length of time it takes for a smart contract to perform its operation, from the beginning to the end of the transaction, is referred to as the execution time. Furthermore, evaluating a smart contract's execution time can reveal any processing power restrictions in the underlying blockchain network. In order to ensure scalability and avoid any performance-related problems, developers can use this to optimize the contract's code to operate within the network's constraints. The performance of the smart contracts are evaluated through the transaction execution time using Ganache EVM and the results are tabulated in Table I.

TABLE I. PERFORMANCE OF THE CONTRACT

| Operation                | From ETH Address | To ETH Address | Average Execution Time in s |
|--------------------------|------------------|----------------|-----------------------------|
| Product Creation         | 0xbC56558f...    | N/A            | 14                          |
| Manufacturer to Supplier | 0xbC56558f...    | 0xcc932c20F... | 13                          |
| Supplier to User A       | 0xcc932c20F...   | 0xe384E1706... | 12.3                        |
| Supplier to User B       | 0xcc932c20F...   | 0xb4407Ff65... | 12.1                        |

### V. CONCLUSION

In the vaccination supply chain, several security-related vulnerabilities could occur. These problems include tampering, counterfeiting, and theft, for instance. Data on vaccines is being stored on the blockchain to solve these problems. By choosing the proper user type and product category, the transaction history for each vaccine may be displayed. In this way, the supply chain data can be greatly safeguarded and secured. The proposed solution can be further enhanced by employing a stable ETH network, minimizing the complexity of the contract to lower gas expenses for each deployment or activity carried out by the user.

### REFERENCES

- [1] Antal, C., Cioara, T., Antal, M. and Anghel, I., 2021. Blockchain platform for COVID-19 vaccine supply management. *IEEE Open Journal of the Computer Society*, 2, pp.164-178.
- [2] Kumar, N., Upreti, K., Upreti, S., Shabbir Alam, M. and Agrawal, M., 2021. Blockchain integrated flexible vaccine supply chain architecture: Excavate the determinants of adoption. *Human Behavior and Emerging Technologies*, 3(5), pp.1106-1117.
- [3] Ng, W.Y., Tan, T.E., Movva, P.V., Fang, A.H.S., Yeo, K.K., Ho, D., San Foo, F.S., Xiao, Z., Sun, K., Wong, T.Y. and Sia, A.T.H., 2021. Blockchain applications in health care for COVID-19 and beyond: a systematic review. *The Lancet Digital Health*, 3(12), pp.e819-e829.
- [4] Kashyap, P., Numan, S.T., Kumar, A., Paul, R., Venkateswarlu, B., Muppalaneni, N.B. and Borah, M.D., 2022. Blockchain and Supply Chain Management: Implementation of COVID Vaccines. In *Prospects of Blockchain Technology for Accelerating Scientific Advancement in Healthcare* (pp. 189-214). IGI Global.
- [5] Kamenivskyy, Y., Palisetti, A., Hamze, L. and Saberi, S., 2022. A Blockchain-Based Solution for COVID-19 Vaccine Distribution. *IEEE Engineering Management Review*, 50(1), pp.43-53.
- [6] Bennacer, S.A., Aaroud, A., Sabiri, K., Rguibi, M.A. and Cherradi, B., 2022. Design and implementation of a New Blockchain-based digital health passport: A Moroccan case study. *Informatics in Medicine Unlocked*, 35, p.101125.
- [7] Khanna, T., Nand, P. and Bali, V., 2022. BEVDS: A Blockchain Model for Multiparty Authentication of COVID-19 Vaccine Beneficiary. In *Innovative Data Communication Technologies and Application* (pp. 857-869). Springer, Singapore.
- [8] Cao, Y., Chen, J. and Cao, Y., 2022. Blockchain-Based Privacy-Preserving Vaccine Passport System. *Security and Communication Networks*, 2022.
- [9] Saidi, D., El Alami, J. and Hlyal, M., 2022. Blockchain for Vaccine Supply Chain: Challenges and Resilient Solution Strategies Facing Covid-19. crisis, 1(5), p.3.
- [10] Loss, S., Singh, H.P., Cacho, N. and Lopes, F., 2022. Using FIWARE and blockchain in smart cities solutions. *Cluster Computing*, pp.1-14.
- [11] Elangovan, P. and Sumalatha, M.R., 2021. Weight based deduplication for minimizing data replication in public cloud storage. *Journal of Scientific & Industrial Research*, 80(03), pp.260-269.
- [12] Velmurugan, K., Yuvaraj, S., Sumalatha, M.R. and Palivela, L., 2022. Supply Chain Financial Risk Management Using Business Intelligence. Available at SSRN 4128710.

- [13] Villarreal, E.D., García-Alonso, J., Moguel, E. and Alegria, J.A.H., 2023. Blockchain for Healthcare Management Systems: A survey on Interoperability and Security. IEEE Access.
- [14] Al-Sumaidae, G., Alkhudary, R., Zilic, Z. and Swidan, A., 2023. Performance analysis of a private blockchain network built on Hyperledger Fabric for healthcare. Information Processing & Management, 60(2), p.103160.
- [15] Karmakar, A., Ghosh, P., Banerjee, P.S. and De, D., 2023. ChainSure: Agent Free Insurance System using Blockchain for Healthcare 4.0. Intelligent Systems with Applications, p.200177.