Vaccine Supply Management using Blockchain

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***Abstract*—In late 2019, we witnessed the apparition of the COVID-19 virus. It first appeared in Wuhan, China and due to people traveling worldwide, it spread globally. The world went into a global lockdown because of its exponential spread and high mortality rates. Social distancing measures, crises in the economy, and healthcare posed many challenges for scientists, researchers, and healthcare workers. To try to combat this situation, multiple vaccines were tried, tested, and created in a very short amount of time. Therefore, a robust yet transparent supply chain system is very crucial in ensuring an efficient vaccination campaign. We propose a blockchain-based vaccination supply chain system to manage the registration, storage and distribution of the vaccines. Blockchain is a decentralized, distributed ledger that records all the transactions happening between the nodes in the network. The data is stored in the ledger in the form of blocks that are linked to each other by hashes, this makes tampering with the data virtually impossible. Blockchain properties will provide a distributed system along with greater privacy, transparency, and authenticity. Smart contracts deployed will help in monitoring and tracking the proper vaccine distribution conditions against the rules and regulations given by the authorities. The tamper-proof nature of blockchain would ensure the supply of proper distribution of only authentic vaccines in a timely manner and traceability of the supply chain will help in increasing the people's trust in the vaccination campaign.**

***Index Terms*—Blockchain, vaccines, supply chain, smart contracts, decentralized, traceability**

I. Introduction

The onset of COVID-19 has completely changed the course of human lives, forcing governments to impose various measures like lockdown, social distancing, etc. to reduce the spread of the virus. Researchers have developed various vaccines to prevent the spread of the virus. However, a robust yet transparent distribution system is critical in the supply of vaccines, to ensure the success of the vaccination campaign. The distribution system should be guarded, ensuring that no one can change the supply chain data in an unauthorized manner. Traceability, which is the ability for anyone to check the entire supply chain of a vaccine batch i.e., where it was manufactured, where it was stored, etc. is also an essential requirement in the system. These properties will not only help in increasing the efficiency of the distribution process and ensure only authentic and proper distribution of vaccines takes place, but also increase the general public's trust in the system and the vaccination campaign. The use of blockchain technology in the supply chain of COVID-19 vaccines will provide both security and traceability to its supply chain management.

The existing systems employ traditional methods in the supply of vaccines. These methods use a central database which records the supply chain of all the vaccines. As the data is only stored in one place, the original records would be lost forever, if any kind of damage is caused to the database. Also, it is not very difficult to manipulate the data as the tamperer only has to break into the database once, after which they can change almost all of the data in the database. Hence, these existing systems are not the most secure way to store vital information like vaccine supply chain details. Traceability features are also difficult to implement in these existing systems.

A blockchain vaccine supply management system is proposed which will aim to overcome the drawbacks of the existing systems. Blockchain is a digital ledger of transactions in which the data is added in blocks and are linked with each other by hash values, and copies of this ledger is distributed in a decentralized network. This makes tampering with the data extremely difficult, as even changing the data in a single block would break the entire chain, and even if someone manages to do that, they will have to do this in all the nodes in the network which is virtually impossible. Also, even in case of a node failure in the network, the data would not be lost nor would the entire system fail. The system would also allow the user to track all the activities in the supply chain.

The objectives of this proposed system are:

- To provide a robust and shielded supply management system for the distribution of COVID-19 vaccines.
- To ensure the proper storage and delivery of the vaccines.
- To make the supply chain transparent and traceable.

- To make the system easy to use for the producers, suppliers and also the beneficiaries.

In the Introduction, chapter 1, the proposal for implementing blockchain technology for the vaccine supply chain was introduced to combat the COVID-19 pandemic. It discussed the drawbacks of traditional supply chains when it comes to factors like transparency and accuracy and put forward the objectives that are kept in mind for developing the project. Chapter 2 presents the Literature Survey and discusses the work done in the field of decentralized supply chain and blockchain technology along with key findings and research papers for the same. In chapter 3, Proposed System, it mentions the importance of having a robust, rapid and a fortified system for a vaccine supply chain and how blockchain could be helpful in providing such features and how it will aim to overcome the shortcomings of the existing systems and gaps found during literature survey. In chapter 4, Design and Methodology, The design of the system is described, along with mentioning and elaborating on the various actors involved in the supply chain process. In Chapter 5, the methodology and procedure used in building the system is explained. The various technologies and dependencies used are also explained. Chapter 6 presents the implementation of the system. Some screenshots of some function in the system are presented and explained. Chapter 7, Conclusion and Future Scope, concludes the project by mentioning the importance of having a blockchain-based system for vaccine supply management due to its transparency in tracing, registration, storage and delivery and discusses the future scope of the project which can be achieved by integrating other technologies to the system.

II. Literature Survey

For the literature survey, research papers from various publishers about blockchain technology and its uses in the supply-chain of COVID-19 vaccines were studied. the papers cover a variety of applications not only limited to the supply chain of COVID-19 vaccines, but also other facets of the COVID-19 pandemic such as contact tracing, distribution of medicines and drugs, detection of falsified drugs,etc, The research papers and their findings are listed below.

1. Horst Treiblmaier - "The impact of the blockchain on the supply chain: a theory-based research framework and a call for action" - Department of International Management, MODUL University Vienna, Vienna, Austria [1]

The paper presents a framework for middle-range theorizing along and explains the potential and implications of blockchain technology in supply chain management and logistics. The framework is built on established economic theories called Principal agent theory (PAT), Transaction cost analysis (TCA), Resource-based view (RBV) and Network theory (NT). These theories are used to derive research questions regarding structural as well as managerial issues and the framework proposes how they can be adapted to blockchain-related questions. The paper also discusses that despite the novelty of it, early adopters of blockchain technology are already finding it "very useful" for their company similar to the adoption of the internet, adoption of blockchain would have a huge impact on supply chain management and logistics.

2. Kelvin K F Tsoi, Joseph J Y Sung, Helen W Y Lee, Karen K L Yiu, Hong Fung, Samuel Y S Wong[1] - "The way forward after COVID-19 vaccination: vaccine passports with blockchain to protect personal privacy" - JC School of Public Health and Primary Care, The Chinese University of Hong Kong, Shatin, Hong Kong; Stanley Ho Big Data Decision Analytics Research Centre, The Chinese University of Hong Kong, Shatin, Hong Kong; Lee Kong Chian School of Medicine, Nanyang Technological University, Singapore [2]

This paper discusses the need for vaccine passports during this age of COVID-19 pandemic. The authors argue that vaccine passports can be a huge tool in reducing the spread of the virus as it helps in only allowing vaccinated individuals to certain places. However, people will be concerned about data privacy, and this is where blockchain comes in. The nature of blockchain allows for the most secure storage of sensitive data, and the use of blockchain in vaccine passports can help reduce people's concerns. In the proposed system, the vaccination details of the beneficiary is added on to the blockchain, which is then used to generate the vaccine passport. The vaccine passport has a QR code which can be scanned by a scanning device in places like malls, movie theatres, etc.

3. Maha FILALI ROTBI, Saad MOTAHHIR, Abdelaziz EL GHZIZAL1 - "Blockchain technology for a Safe and Transparent Covid-19 Vaccination" - Innovative Technologies Laboratory, EST, SMBA University, Fez, Morocco; Engineering, Systems and Applications Laboratory, ENSA, SMBA University, Fez, Morocco [3]

The authors of this paper propose a supply chain system for COVID-19 vaccines which uses blockchain and IoT. IoT is used for monitoring the storage factors of the vaccines such as temperature, humidity, etc. The system defines 5 roles, Manufacturer, Distributor, Medical Center, Doctor and Patient/Beneficiary, each performing unique actions. The paper also explains how and why blockchain is useful for the supply chain management of COVID-19 vaccines. It also explains the architecture of the system and what each layer such as physical layer, device layer, etc. would do. However, the paper only proposes the ideas, but does not have any implementation of a working system.

4. Shirajus Salekin Nabila, Md. Sabbir Alam Prana, Ali Abrar Al Haquea, Narayan Ranjan Chakrabortya, Mohammad Jabed, Morshed Chowdhuryb, Md Sadek Ferdousc - "Blockchain-based Covid Vaccination Registration and Monitoring" - a Daffodil International University, Dhaka 1207, Bangladesh b La Trobe University, VIC, 3086, Australia c BRAC University, Dhaka 1212, Bangladesh [4]

The system proposed here is a blockchain based

vaccination system. It defines 5 actors of the system, namely Authority/Government, Issuer, Vaccine Provider, Holder(Beneficiary), Verifier. This system takes care of the registration, vaccination, and monitoring part, as the holders are given a vaccine certificate with a QR code. However, mechanism for transport and distribution of vaccines is not defined here. Another key feature of this system is the Priority mechanism. The Authority/Government would assign priority to the Holders in the network based on age/profession(Front-line workers, essential workers, etc), and are given vaccines according to that priority set by the government.

5. Zehuan Qiu and Yifan Zhu - "A Novel Structure of Blockchain Applied in Vaccine Quality Control: Double-Chain Structured Blockchain System for Vaccine Anticounterfeiting and Traceability" - College of Cyberspace Security, Hangzhou Dianzi University, Hangzhou 310018, Zhejiang, China; London School of Hygiene and Tropical Medicine Keppel Street, London WC1E 7HT, UK [5]

This paper proposes a system that aims to provide anti-counterfeiting as well as traceability to the vaccines by the use of a double-chain structured blockchain system. The system uses two blockchains, one is a public blockchain and the other is a private blockchain. The two blockchains are used for two modules. The public blockchain is used for the traceability module of the system, providing traceability to the vaccines and allowing anyone to verify the supply chain of a vaccine batch. The private blockchain is used for the transfer identification module. This blockchain is used for anti-counterfeiting purposes.

6. Kevin A. Clauson, Elizabeth A. Breeden, Cameron Davidson, Timothy K. Mackey- "Leveraging Blockchain Technology to Enhance Supply Chain Management in Healthcare: An Exploration of Challenges and Opportunities in the Health Supply Chain" - Health Care Informatics, Lipscomb University College of Pharmacy and Health Sciences, Tennessee, USA, PioneerRx, Tennessee, USA, UC San Diego – School of Medicine, San Diego, California, USA. [6]

This paper presents an overview of the opportunities and challenges of adopting blockchain technology in the supply chain field, with extra emphasis on medical and healthcare products/devices. The paper discusses all the requirements of a supply chain system and assesses whether the integration of blockchain fulfils them and is compatible with the development of a robust supply chain. The authors also talk about the existing blockchain supply chain systems and compares their features.

7. CLAUDIA ANTAL (Member, IEEE), TUDOR CIOARA (Member, IEEE), MARCEL ANTAL (Member, IEEE), AND IONUT ANGHEL (Member, IEEE) - "Blockchain Platform For COVID-19 Vaccine Supply Management" - Computer Science Department, Faculty of Automation and Computer Science, Technical University of Cluj-Napoca Cluj-Napoca, Romania [7]

The authors here propose a system similar to that of [3] as this system also makes use of blockchain and IoT technology to carry out the distribution of the COVID-19 vaccines. The actors defined here are vaccine Producer, Distributor, Storage, Medical Centre, Doctors and Beneficiaries. IoT is used to monitor the storage conditions of the vaccines and once vaccinated, the beneficiaries can enter any side-effects they are facing post vaccination. This paper also provides and explains the smart contracts being used for all the actions being carried out in the system.

8. Andrei Carniel, Gustavo Leme, Juliana de Melo Bezerra and Celso Massaki Hirata - "A Blockchain Approach to Support Vaccination Process in a Country" - Computer Science Department, ITA, Sao José dos Campos, Brazil [8]

In this paper, the authors are proposing a blockchain-based vaccination system. A prototype using Ethereum blockchain has been built by the authors which also defines five different types of actors of the system, namely, the Government, Enterprise, Vaccine Center, Nurse/Doctor and Person/Beneficiary and their actions are also explained. The paper also discusses the details necessary to be added to the blockchain and discusses the use of dependencies required in the development of their prototype.

9. Patrick Sylim, MD; Fang Liu, MS; Alvin Marcelo, MD; Paul Fontelo, MD, MPH - "Blockchain Technology for Detecting Falsified and Substandard Drugs in Distribution: Pharmaceutical Supply Chain Intervention" - National Library of Medicine, National Institutes of Health, Bethesda, MD, United States; Standards and Interoperability Lab for Asia, University of the Philippines, Manila, Philippines [9]

This paper proposes the use of blockchain in the monitoring of the authenticity of drugs and vaccines. The authors have developed a prototype which aims to detect falsified or substandard drugs in the supply chain. Swarm is employed as the Distributed File System(DFS). Two instances were developed, one in Ethereum and one in Hyperledger Fabric. The development and testing of the prototype was done in a simulated network.

10. Jorge Medina , Student Member, IEEE, Roberto Cessa-Rojas , Senior Member, IEEE, and Vatcharapan Umpaichitra - "Reducing COVID-19 Cases and Deaths by Applying Blockchain in Vaccination Rollout Management" [10]

The authors of this paper make an argument that the number of COVID-19 cases and fatalities can be reduced with the use of blockchain in the vaccination process and contact tracing. The authors make use of the SEIR and SEIR-VB models to determine the spread of the COVID-19 infection and present the number of cases in a variety of cases dependent on parameters like, mask wearing, social distancing, blockchain in vaccines rollout, etc.

11. Abhishek Sharma and Shashi Bahl and Ashok Kumar Bagha and Mohd Javaid and Dinesh Kumar Shukla and

Abid Haleem- "Blockchain technology and its applications to combat COVID-19 pandemic"[11]

The application of blockchain in not only vaccine supply chain, but also in other fields to combat the COVID-19 endemic are discussed in this paper. It discusses the applications such as vaccine supply chain management, traceability, disease control, supply chain of other crucial medical products, transparency during treatment of patients, tracking of healthcare instruments, storage and transfer of treatment of related information, etc.

Analysis

By analysing the findings of the literature survey, 3 common gaps were found which our proposed system aims to address. They are as follows:

- The previous systems proposed didn't have mechanisms which emphasized on the second dose. Features like second vaccine dose date and the beneficiary's vaccination status being reverted back to "Not Vaccinated" from "Partially Vaccinated" if they fail to take the vaccine in the specified time period, were not found.
- They didn't have any mechanism in place to enforce the on-time and proper delivery. Without a reward or penalty system for the punctuality of the delivery, the supply chain has to rely exclusively on the transporter to deliver the vaccines on time.
- The systems only worked one-way, i.e., the vaccine producers were the ones sending vaccines without any input from the other parties as opposed to the medical centres requesting/ordering for more vaccines. This is important as different centres will require vaccines at different frequencies depending on the population of the location they are in.

III. Proposed System

A. Problem Definition

The supply chain management system for something as essential and important as COVID-19 vaccines requires a robust and rapid system which is not only safeguarded but also transparent. The system should not permit any malicious individual or entity to change the data already stored. The system should also provide traceability for all the vaccines, such that the whole supply chain can be checked by the general public. As there is skepticism amongst the population about the vaccination campaigns and their authenticity, it is important that the mentioned properties are achieved by the system to increase their trust in the vaccination process and to get everyone to be vaccinated as soon as possible. The traditionally used systems only achieve these properties to a limited extent.

B. Proposed System

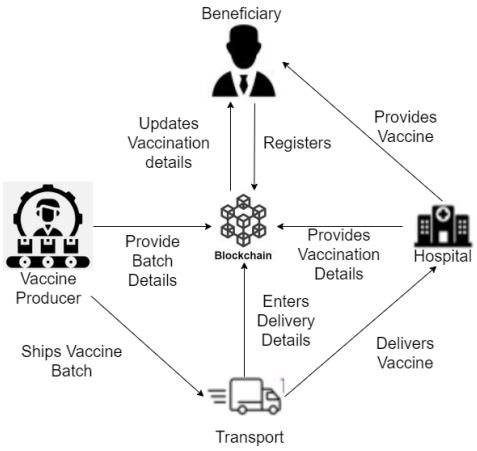

Fig. 1. Proposed System

A blockchain-based vaccine supply chain management system is proposed here to achieve the criteria mentioned in the problem statement. The use of blockchain would make the system achieve these features to their full extent. The decentralized nature of blockchain makes the system resistant to any kind of data loss, as the data is stored in a ledger which is distributed with all the nodes/peers of the network as opposed to a central database. Therefore, losing data or total failure of the system is virtually impossible. The data stored in the ledger is stored in "blocks" which are linked to each other by hash pointers. The hash pointers rely on transaction details like sender, receiver, transaction data and the hash of the previous block. Meaning, if an individual tries to alter any data in the blockchain, the hash value of that block changes which will break the blockchain, which will be detected by the other nodes. This along with decentralized nature, makes the system fortified. The smart contracts deployed on the blockchain will store the supply chain details, which will provide traceability to the system.

The system has four actors who interact with the blockchain and add supply chain details to the blockchain. These four actors are:

- Vaccine Manufacturers: The vaccine manufacturer is the actor which produces the vaccine and is the starting point of the supply chain. The responsibilities of manufacturer include registering a brand, producing vaccines, entering the vaccine batch details, and sending the batch for transport.
- Transporters: The transporter will pick up the batch from the manufacturer and deliver it to the hospital. If they fail to deliver the vaccine before the time specified by the shipping order, the transporter would receive a penalty.
- Hospitals: The hospital can order vaccines of any quantity from any manufacturer in the network. Hospitals upon receiving the vaccine batch will add the batch to their stock. The hospital will also be the one vaccinating the beneficiary and updating their details.
- Beneficiaries: The beneficiary/patient is the one who receives the vaccine at the end. They can book vaccines of

their choice from any hospital in the system. The website will also provide vaccine certificates to the beneficiary.

C. Overcoming drawbacks of existing works

To overcome the drawbacks mentioned in the analysis of literature survey, the following features have been integrated in the proposed system:

- If the transporter fails to deliver the vaccine before the time mentioned by the shipping order, the transporter would receive a penalty. This penalty count would be visible whenever a manufacturer is viewing transporter profiles to transport the vaccines.
- The system provides the ability to place orders, such as vaccine orders from hospital to manufacturer, shipping orders from manufacturer to transporter, vaccine bookings from beneficiary to hospital.
- It displays the time range in which the next dose has to be taken by the beneficiary, also restricting the user from making any booking for vaccination outside of that time range. Also, the users will be prevented from getting a vaccine of a brand different than their previous dose.

IV. System Design

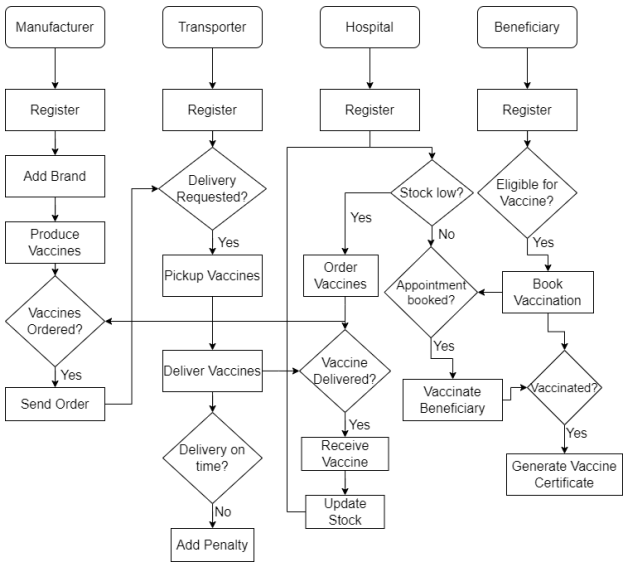

Fig. 2. ER Diagram

Fig. 2. is the ER diagram which shows the working of the supply chain of this system. It has the four aforementioned actors all taking part in the supply of vaccines and input the supply chain details of the vaccine at each stage. The working of the supply chain is as follows:

- Firstly, all types of actors need to register themselves to the system using their Metamask wallet accounts. They need to input their organization name and location for registering, full name, age and location for in case of Beneficiary.
- The manufacturer registers a brand of vaccine to the system by inputting all relevant details such as brand name, number of doses required, shelf life, etc. Once a brand has been registered any manufacturer in the system is allowed to produce vaccines for the brand.
- When the manufacturer produces vaccines, they enter it into the system by choosing the brand and number of doses in the batch. The vaccines inherit all properties from the brand chosen for eg. the expiry date, number of doses required, etc.
- Hospitals can order vaccines from a manufacturer by choosing the brand name, manufacturer, quantity, etc. The order also asks for the time in which the vaccines need to be delivered.
- On receiving the order, the manufacturer chooses a transporter to deliver the vaccine batches to the Hospital.
- The transporter then picks up the batch from the manufacturer and delivers it to the Hospital. If the delivery time exceeds the time mentioned in the vaccine order, the transporter would receive a penalty.
- On receiving the shipment, the hospital adds the batch to its vaccine stock and the details are added to the system.
- The beneficiary can book a vaccination appointment, provided they are eligible for the vaccination by choosing a brand of their choice and any hospital in the network. After booking, they can get vaccinated from the hospital and they can download a vaccine certificate.

V. Methodology

The proposed system is a blockchain-based vaccine supply management system, consisting of various components which interact with each other such as the Rinkeby testnet in which the smart contracts are deployed and data is stored, and a website which acts as a front-end for the system for the user to interact with. It was developed by following the the procedure given below:

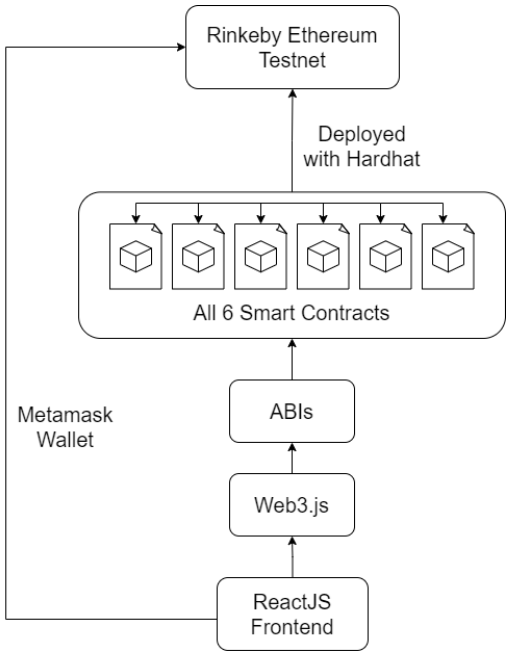

Fig. 3. System Diagram

A. Creating Smart Contracts

The smart contracts are written in the Solidity language, which is a statically typed, curly-braces programming language designed for the development of smart contracts that run on the Ethereum blockchain. The smart contracts were written and developed on Remix IDE. Remix is a free online IDE that is used to develop and test smart contracts. In total six smart contracts have been written, four for each actor i.e. Manufacturer, Transporter, Hospital and Beneficiary, one for vaccines, and one which contains all the functions for hospitals ordering vaccines, manufacturer sending the order, etc.

B. Rinkeby Testnet

Rinkeby is a Ethereum Test Network which is a blockchain network with ether of zero value. It is used by developers to develop and test their blockchain applications before deploying them to the mainnet.

C. Compiling and deploying smart contracts

The compilation and deployment of the smart contracts to the test network is done using Hardhat. On compilation, ABI(Application Binary Interface) is generated by Hardhat which is required in integrating the front-end to the system. After compiling, Hardhat deploys each contract to different addresses, which is used by the smart contracts to interact with themselves, and by Metamask to send transactions, etc.

D. Developing Front-end

A website is developed using ReactJS which acts as the front-end of the system. The website has different profile pages for different actors which provides them options to perform tasks specific to their profile.

E. Web3.js

The website is integrated with smart contracts with the use of web3.js module. Web3.js is a collection of libraries which allow a user to interact with a local or remote blockchain. The contract addresses and ABIs generated by Hardhat are used by the web3 scripts to integrate the front-end to the smart contracts.

F. Metamask Wallet

The Metamask wallet browser extension is required for the operation of the system. Metamask is a cryptocurrency wallet used to interact with the blockchain. Any data being added to the blockchain requires gas fees to be payed. Metamask allows the user to pay these gas fees.

VI. Implementation

The implemented system is a supply management system for COVID-19 vaccines which records the supply chain of each vaccine batch. A ReactJS website is developed which acts as the front-end for the system. It has different profile page for each actor and different tabs for different functions such as registering a brand, ordering vaccine batches, etc. The following screenshots depict the final results of the system:

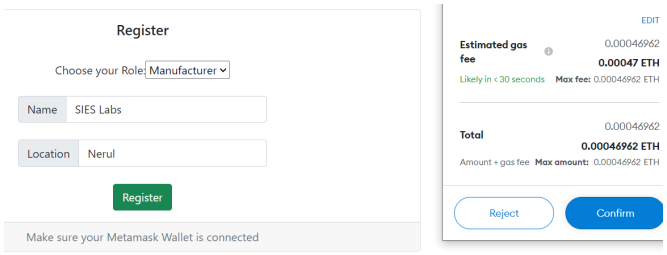

Fig. 4. Registering a Manufacturer to the System

Fig. 4. shows the sign up page, where any user can sign up to the system using their Metamask account. The user gets to choose this role and enter their details. On submitting, the Metamask transaction confirmation window pops up to confirm the payment of gas fees.

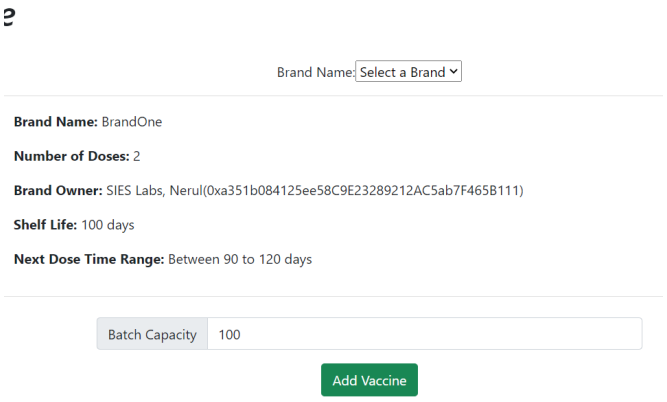

Fig. 5. Adding a Vaccine Batch to the System

Fig. 5. shows how the manufacturer can add a vaccine batch to the system. The manufacturer selects the a brand from the list of brands registered on the system which shows the details of the brand such as its shelf life, required doses, etc. The manufacturer just needs to input the number of doses in the batch and the vaccines inherit the properties from the selected brand.

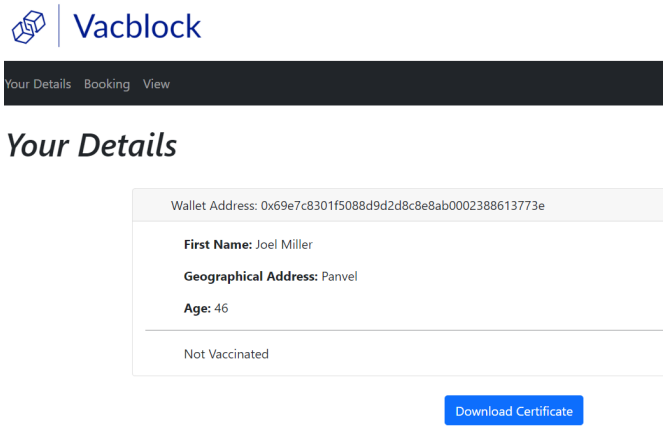

Fig. 6. Beneficiary Details pre-Vaccination

Fig. 6. shows the beneficiary details listed in their page. This is before the beneficiary has taken any vaccine.

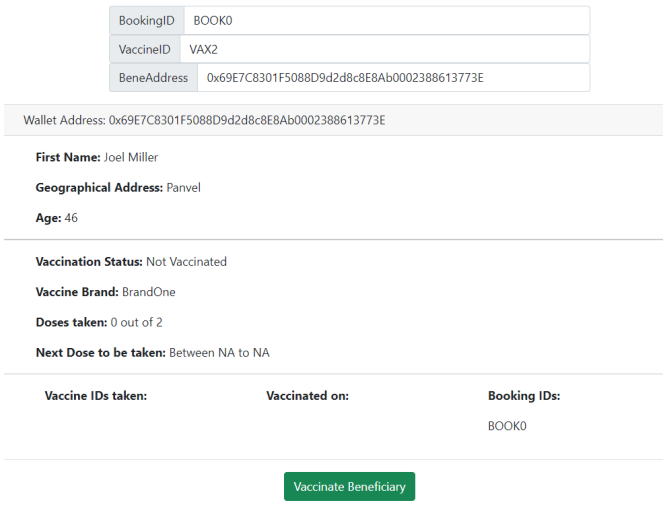

Fig. 7. Vaccinating Beneficiary

Fig. 7. shows the vaccination details of beneficiary being entered by the hospital. The hospital enters the booking ID, beneficiary's wallet address and vaccine batch ID that the beneficiary will be receiving. Upon entering the beneficiary's wallet address the system shows the beneficiaries details for the hospital to verify whether the vaccine being given matches with the vaccine the beneficiary has booked or previously taken.

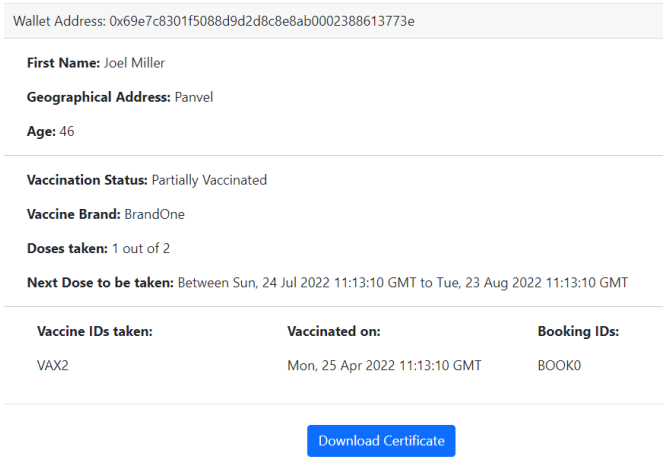

Fig. 8. Beneficiary Details post-Vaccination

Fig. 8. shows the updated beneficiary details. The page shows the brand of vaccine the beneficiary has taken and the vaccination status, i.e. partially vaccinated, fully vaccinated. The page also shows when the beneficiary needs to take the next dose of the vaccine and how many doses are left.

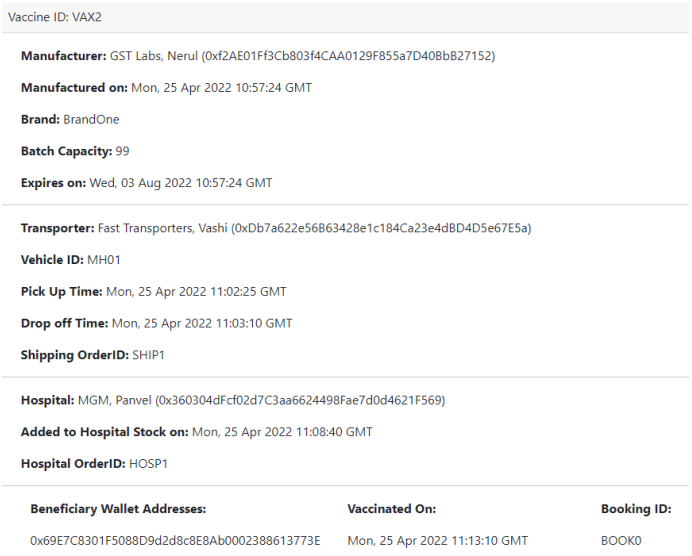

Fig. 9. Vaccine Supply Chain Details

Fig. 9. shows the viewing page where the user can see the entire supply chain details of the vaccine batch by entering the vaccine batch ID. It shows when the batch was manufactured, when it was picked up for transportation, when it was delivered to the hospital, who transported the batch, which beneficiaries received the vaccine from this batch and when, etc. The page also shows other details such as any actors details, any orders details, etc.

VII. Conclusion

A system for the efficient supply of COVID-19 vaccines was proposed. It uses blockchain technology for transparent tracing of COVID-19 vaccine supply chain and records all essential details of the supply chain such as production details, transportation details, etc. It aims to overcome the limitations of traditional systems by providing essential features such as traceability, tamper-proofness which is critical in the distribution of COVID-19 vaccines as well in building the trust of the general public. The proposed model captures the whole vaccination process, starting from user registration, vaccine production to beneficiary getting vaccinated. The decentralized nature of this system ensures that the vaccination process is never hindered and its immutable nature ensures that the data cannot be tampered with. Adoption of blockchain in vaccine supply management enhances the security of the vaccination process and helps reduce the spread of the pandemic.

However, there is also scope for improvement in this system which can be realized by integrating other technologies such as IoT(Internet of Things) in the system. It would allow the monitoring of various additional conditions such as temperature, humidity, physical condition and other storage conditions. Live-time monitoring of GPS could also be added to the system which will also be very beneficial to the system as it will increase the traceability and transparency of the system even more.

REFERENCES

[1] Horst Treiblmaier - "The impact of the blockchain on the supply chain: a theory-based research framework and a call for action" - Department of International Management, MODUL University Vienna, Vienna, Austria.

[2] Kelvin K F Tsoi, Joseph J Y Sung, Helen W Y Lee, Karen K L Yiu, Hong Fung, Samuel Y S Wong - "The way forward after COVID-19 vaccination: vaccine passports with blockchain to protect personal privacy" - JC School of Public Health and Primary Care, The Chinese University of Hong Kong, Shatin, Hong Kong; Stanley Ho Big Data Decision Analytics Research Centre, The Chinese University of Hong Kong, Shatin, Hong Kong; Lee Kong Chian School of Medicine, Nanyang Technological University, Singapore.

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[4] Shirajus Salekin Nabila, Md. Sabbir Alam Prana, Ali Abrar Al Haquea, Narayan Ranjan Chakrabortya, Mohammad Jabed, Morshed Chowdhuryb, Md Sadek Ferdousc - "Blockchain-based Covid Vaccination Registration and Monitoring" - a Daffodil International University, Dhaka 1207, Bangladesh b La Trobe University, VIC, 3086, Australia c BRAC University, Dhaka 1212, Bangladesh.

[5] Zehuan Qiu and Yifan Zhu - "A Novel Structure of Blockchain Applied in Vaccine Quality Control: Double-Chain Structured Blockchain System for Vaccine Anticounterfeiting and Traceability" - College of Cyberspace Security, Hangzhou Dianzi University, Hangzhou 310018, Zhejiang, China; London School of Hygiene and Tropical Medicine Keppel Street, London WC1E 7HT, UK.

[6] Kevin A. Clauson, Elizabeth A. Breeden, Cameron Davidson, Timothy K. Mackey- "Leveraging Blockchain Technology to Enhance Supply Chain Management in Healthcare: An Exploration of Challenges and Opportunities in the Health Supply Chain" - Health Care Informatics, Lipscomb University College of Pharmacy and Health Sciences, Tennessee, USA, PioneerRx, Tennessee, USA, UC San Diego – School of Medicine, San Diego, California, USA.

[7] CLAUDIA ANTAL (Member, IEEE), TUDOR CIOARA (Member, IEEE), MARCEL ANTAL (Member, IEEE), AND IONUT ANGHEL (Member, IEEE) - "Blockchain Platform For COVID-19 Vaccine Supply Management" - Computer Science Department, Faculty of Automation and Computer Science, Technical University of Cluj-Napoca Cluj-Napoca, Romania.

[8] Andrei Carniel, Gustavo Leme, Juliana de Melo Bezerra and Celso Massaki Hirata - "A Blockchain Approach to Support Vaccination Process in a Country" - Computer Science Department, ITA, Sao José dos Campos, Brazil.

[9] Patrick Sylim, MD; Fang Liu, MS; Alvin Marcelo, MD; Paul Fontelo, MD, MPH - "Blockchain Technology for Detecting Falsified and Substandard Drugs in Distribution: Pharmaceutical Supply Chain Intervention" - National Library of Medicine, National Institutes of Health, Bethesda, MD, United States; Standards and Interoperability Lab for Asia, University of the Philippines, Manila, Philippines.

[10] Jorge Medina , Student Member, IEEE, Roberto Cessa-Rojas , Senior Member, IEEE, and Vatcharapan Umpaichitra - "Reducing COVID-19 Cases and Deaths by Applying Blockchain in Vaccination Rollout Management".

[11] Abhishek Sharma and Shashi Bahl and Ashok Kumar Bagha and Mohd Javaid and Dinesh Kumar Shukla and Abid Haleem- "Blockchain technology and its applications to combat COVID-19 pandemic".