Blockchain-Based Vaccination Record Tracking System

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***Abstract*—Blockchain technology is basically a decentralized database maintained by applicable parties and has been extensively used in colorful scripts similar as logistics and finance. In terms of operations in the medical field, it's getting increasingly important because the case's symptoms may be related to a certain vaccine. Whether the case has been vaccinated with this vaccine will lead to different individual results by the croaker. This study proposes a traceable blockchain-grounded vaccination record storehouse and sharing system. In the proposed system, the case gets the vaccination at any legal clinic and the VR can be saved accompanied by the hand into the blockchain center, which ensures traceability. When the case visits the sanitarium for treatment, the croaker can gain the details of the VR from the blockchain center and also make an opinion. The security of the proposed system will be defended by the programmed smart contracts. The proper record storage after encryption will ensure data privacy, integrity and security. Blockchain tracebility uses block-chain technology to record the movement of a product in the supply chain.**

Keywords*—Blockchain technology, decentralized, vaccine record tracking, integrity, smart contracts, vaccination record storage, traceability

I. Introduction

The global spread of Coronavirus Disease 2019 (COVID-19) in 2020 has posed unprecedented challenges to the healthcare sector, highlighting the use of innovative solutions to mitigate the spread of infections [1]. Contact tracing applications have emerged as a potential tool to break the chain of COVID-19 infections by identifying close contacts of positive cases and informing them about the possibility of being infected [2]. However, current contact tracing technologies face challenges in terms of privacy, accountability, and transparency, which can hinder their effectiveness and user adoption [3]. Our proposed method is noteworthy for its ability to track the origin and path of transactions related to vaccinations before they are used, in addition to preventing the circulation of counterfeit vaccines.

In this research paper, we propose a blockchain-based contact tracing solution that leverages the intrinsic features of blockchain technology to address the deficits of current contact tracing technologies [4]. Our solution aims to respect user privacy, provide transparency, and enable accountability by leveraging the decentralized, transparent, and immutable nature of blockchain technology [5]. Specifically, we utilize this blockchain with the smart contracts to eliminate the third-party servers, centralization, and identity abuse. Convergence algorithms, like proof of work or proof of stake, are used by the blockchain network to reach consensus on the ledger's current state and stop illegal changes. The accuracy and openness of the vaccination tracking data are therefore guaranteed.

Our solution utilizes the programmable logic of smart contracts to ensure transparency and trust among the different participants. All transactions on the blockchain are signed by their creators, holding every on-chain participant accountable for their actions [6]. By leveraging the immutable logs of the distributed ledger, our solution enforces transparency and trust, and eliminates the risks associated with centralized storage of user data [7]. The system architecture of our suggested application, Vaccine Tracker, which makes use of blockchain technology to offer complete visibility and transparency throughout the COVID vaccination supply chain. To guarantee the precision and dependability of vaccine tracking data, the Vaccine Tracker system uses a variety of algorithms for supply chain tracking and validation.

In this paper, we present the architecture, design, and implementation details of our blockchain-based contact tracing solution [8]. We also discuss the potential of blockchain technology in mitigating the spread of infections during the COVID-19 pandemic and highlight the advantages of using Ethereum blockchain with smart contracts for contact tracing [9]. The proposed architecture includes manufacturer Component which adds relevant information. The system verifies the information supplied by the manufacturer, such as location tracking and QR code generating. Our research contributes to the growing body of literature on blockchain technology in healthcare and contact tracing, and provides requirements for future research and practical applications [10]. Utilising cryptographic methods like digital signatures and hashing, the algorithm verifies the security and legitimacy of the information it has acquired from the blockchain. This guarantees the immutability and tamper-proof nature of the data recorded on the blockchain.

II. Related Work

Several studies and projects have explored the want of blockchain in healthcare, including its application in COVID-19 vaccination efforts. Here, we highlight some of the notable related work and contributions in the field.

A. Blockchain-Based Vaccination Verification Systems

Several blockchain-based systems have been used for verifying COVID-19 vaccination status. For example, the "VaxiChain" [11] aims to create a blockchain-based vaccination verification system that allows individuals to store their vaccination records in a secure and tamper-proof manner. The system uses smart contracts to automate the verification process, allowing healthcare providers, employers, and other entities to verify an individual's vaccination status without accessing their private health information. Another example is the "V-Health Passport" [12], which uses blockchain to enable secure storage and sharing of vaccination records, as well as other health-related data, with the aim of facilitating safe travel and other activities during the pandemic. Verify an individual's vaccination status without accessing their private health information. Another example is the "V-Health Passport", which uses blockchain to enable secure storage and sharing of vaccination records, as well as other health-related data, with the aim of facilitating safe travel and other activities during the pandemic.

B. Blockchain-Based Vaccine Distribution and Tracking

Blockchain has also been used as a solution for vaccine distribution and tracking in resource-constrained settings. The "Vaccination Supply Chain Management on Blockchain" project [13] proposes a blockchain-based system for tracking vaccine distribution, ensuring that vaccines reach their intended destinations and are administered to the right individuals. The system uses smart contracts to automate processes such as vaccine allocation, inventory management, and cold chain monitoring, thereby increasing transparency, efficiency, and accountability in the vaccine supply chain. Another example is the "Blockchain-Enabled COVID-19 Vaccine Delivery System" [14], which proposes a blockchain-based platform for tracking COVID-19 vaccines from the manufacturer to the end recipient, with the aim of reducing vaccine wastage, improving supply chain visibility, and preventing counterfeit vaccines.

C. Privacy-Preserving Approaches in Blockchain-Based Healthcare Systems

Privacy and security are critical concerns in healthcare, and several studies have proposed privacy-preserving approaches in the context of blockchain-based healthcare systems. For example, the "MediBloc" [15] proposes a blockchain-based health information that uses advanced cryptography techniques to protect patient privacy while enabling secure sharing of health data among authorized parties. The "HealthChain" [16] proposes a privacy-preserving blockchain-based system for storing and sharing electronic health records, using techniques such as zero-knowledge proofs and secure multi-party computation to protect patient confidentiality. These approaches highlight the potential of blockchain in maintaining data privacy and security in healthcare settings, including COVID-19 vaccination efforts.

D. Challenges and Limitations

Despite the potential usages, there are requirements and limitations associated with the use of blockchain in healthcare, including COVID-19 vaccination efforts. Interoperability, scalability, privacy, security, and regulatory compliance are some of the main challenges that need to be addressed. Several studies and projects have highlighted these challenges and proposed solutions to overcome them. For example, the "HL7 Fast Healthcare Interoperability Resources (FHIR) and Blockchain" [17] proposes a framework for combining blockchain with existing healthcare standards, such as FHIR, to enable interoperability. The "Scalable and Interoperable Blockchain-Based Healthcare Systems" [18] proposes a scalable and interoperable blockchain architecture for healthcare, using techniques such as sharding and cross-chain communication. The "Privacy-Preserving Blockchain-Based Consent Management System for Healthcare" [19] proposes a consent management system that uses blockchain and smart contracts to manage patient consent in a privacy-preserving manner. These efforts highlight the ongoing research and development in addressing the challenges and limitations of blockchain in healthcare [20].

III. System Design

In this part, the system design of our proposed Vaccine Tracker application, which utilizes blockchain technology to provide end-to-end visibility and transparency in the COVID vaccine supply chain.

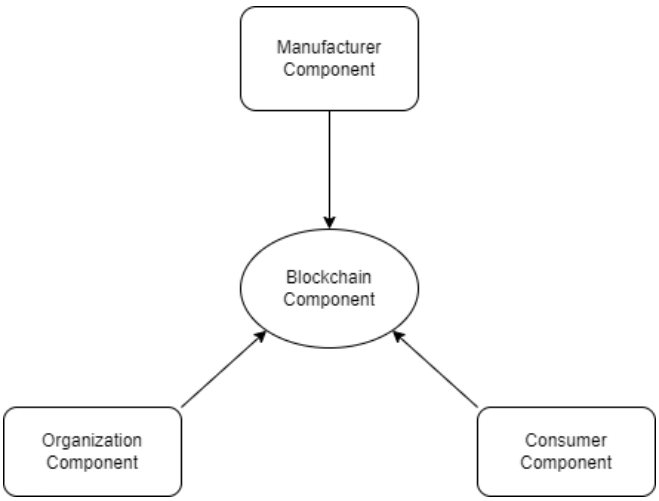

Fig. 1. System architecture.

Above Fig. 1 represents the proposed architecture.

A. Manufacturer Component

- The manufacturer adds a new vaccine batch to the system by entering relevant information, such as batch number, manufacturing date, expiration date, and other details.
- The system validates the data provided by the manufacturer, including QR code generation and location tracking data.
- Once the data is validated, the vaccine batch information is stored on the blockchain and shared with relevant stakeholders in the supply chain.

B. Organization Component

- Organizations involved in the vaccine supply chain, such as distributors, warehouses, and healthcare providers, can access the vaccine information from the blockchain.

- They can scan the vaccine shipments using QR code validation algorithms to verify the authenticity of the vaccines and record the location and condition data.
- The validated data is encrypted and stored on the blockchain for further validation and tracking.

C. Consumer Component

- Consumers can scan the QR code on the vaccine product using a mobile application.
- The QR code validation algorithm verifies the authenticity of the QR code data against the information stored on the blockchain.
- If the QR code is validated, the consumer can view exact information about the vaccine's provenance, including batch number, manufacturing date, and other details.

D. Blockchain Component

- The blockchain serves as a distributed ledger that securely stores the vaccine tracking data, including batch information, location data, and QR code validation results.
- The blockchain is encrypted and protected using cryptographic techniques, ensuring data security and integrity.
- Smart contracts programmed in Solidity language validate the data and enforce predefined rules and conditions

The proposed system employs a decentralized architecture using the Ethereum blockchain, which allows for transparent and tamper-proof recording of the vaccine's journey from the manufacturer to the hospital. The system comprises the following key components:

1) Vaccine Tracking: In this component, the vaccine's whereabouts at every freight hub, warehouse, and airport along its journey are recorded on the blockchain. This is achieved by utilizing smart contracts programmed in Solidity, which automatically record the vaccine's location, temperature conditions, and other relevant information at each step of the supply chain. This creates a transparent and immutable record of the vaccine's provenance, ensuring its authenticity and quality.

2) QR Code Scanning: At the consumer end, customers can simply scan the QR code of the vaccine product to access complete information about its provenance. The QR code acts as a unique identifier for each vaccine, and the information received from the blockchain includes details such as the manufacturer, shipping route, temperature conditions, and chain of custody. This empowers consumers to identify the authenticity of the vaccine before purchasing, mitigating the risk of counterfeit vaccines and ensuring their safety.

3) Blockchain Network: The blockchain network serves as the pillar of the system, consisting of a distributed network of nodes that maintain a shared ledger of vaccine tracking records. The blockchain network utilizes consensus algorithms, such as proof of work or proof of stake, to achieve agreement on the state of the ledger and prevent unauthorized modifications. This ensures the integrity and transparency of the vaccine tracking data.

4) Smart Contracts: Smart contracts are self-executing scripts that run on the blockchain and enable automated verification of vaccination records. In our system, smart contracts are used to define the rules and conditions for verifying vaccination status, such as checking the validity of the digital signatures, verifying the authenticity of the vaccine administered, and ensuring compliance with vaccination protocols.

5) User Interface: The system includes user interfaces and experiences for different stakeholders, such as vaccine manufacturers, logistics providers, hospitals, and consumers. These interfaces provide a user-friendly way to interact with the system, allowing stakeholders to input and retrieve vaccine tracking data, as well as verify the authenticity of vaccines through QR code scanning.

IV. Implementation Details

This section presents the used algorithms along with their implementation and coding details. The solidity code is written and tested with the Remix IDE. The Vaccine Tracker system employs various algorithms for supply chain tracking and validation to ensure the accuracy and reliability of vaccine tracking data. These algorithms include:

A. Location Tracking Algorithm

1) When a vaccine shipment is received at a freight hub or a vaccination center, the location tracking algorithm is triggered to collect the precise location data of the vaccines.

2) The algorithm utilizes GPS or other location tracking technologies, such as RFID (Radio Frequency Identification) or IoT (Internet of Things) devices, to collect the real-time location data of the vaccine shipment.

3) The location data, which may include latitude, longitude, timestamp, and other relevant information, is encrypted using cryptographic algorithms to use data security and privacy.

4) The encrypted location data is then stored as a transaction on the Ethereum blockchain, using a smart contract specifically designed for vaccine tracking. The transaction includes the encrypted location data, as well as other relevant information, such as the batch number, manufacturing date, and vaccine details.

5) The smart contract validates the encrypted location data to ensure its integrity and authenticity. This validation is done using cryptographic techniques, such as hashing and digital signatures, to verify the data against predefined rules and cryptographic keys.

6) Once the location data is validated, it is combined to the blockchain, creating a transparent and immutable record of the vaccine's journey. The location data is now available for real-time tracking and validation by authorized users, such as healthcare providers, regulators, and consumers.

7) The authorized users can access the location data from

the blockchain using a mobile app or a web interface, which decrypts the data using the appropriate cryptographic keys. The decrypted location data can then be displayed on a map or other visual representations, allowing users to track the movement of vaccines at each stage of the supply chain.

8) Any changes or updates to the location data, such as when the vaccine shipment moves to a new location, are recorded as new transactions on the blockchain, creating a chronological and auditable history of the vaccine's journey.

9) The location tracking algorithm continues to collect and record the precise location data of the vaccine shipment at each stage of the supply chain, ensuring real-time tracking and validation of vaccine movements throughout the entire supply chain process.

10) In case of any discrepancies or anomalies in the location data, such as a vaccine shipment being diverted or tampered with, the algorithm can trigger alerts or notifications to authorized users, enabling timely intervention and resolution of any issues.

Overall, the Location Tracking Algorithm in the Vaccine Tracker system uses GPS or other location tracking technologies to collect and record the precise location data of vaccines at each stage of the supply chain. The location data is encrypted and stored on the blockchain, allowing for real-time tracking and validation of vaccine movements, ensuring transparency, integrity, and authenticity of vaccine tracking data.

B. QR Code Validation Algorithm

1) When a consumer scans a QR code on a vaccine product using a mobile app or a web interface, the QR code validation algorithm is triggered to verify the authenticity of the scanned QR code.

2) The algorithm extracts the data from the scanned QR code, which will include requirement such as the batch number, manufacturing date, and other details of the vaccine.

3) The algorithm accesses the Ethereum blockchain, where the vaccine tracking data is stored, and retrieves the relevant information for the scanned QR code from the blockchain.

4) The retrieved information from the blockchain is compared with the data extracted from the scanned QR code to verify if they match. This comparison includes checking the batch number, manufacturing date, and other details to ensure that the QR code corresponds to a genuine vaccine.

5) The algorithm uses cryptographic techniques, such as hashing and digital signatures, to validate the authenticity and security of the data retrieved from the blockchain. This ensures that the data stored in the blockchain is tamper-proof and cannot be manipulated.

6) If the data extracted from the scanned QR code matches the information stored in the blockchain, the algorithm confirms that the QR code corresponds to a genuine vaccine and provides a validation result to the consumer, indicating that the vaccine is authentic.

7) If the data does not match, the algorithm raises an alert or notification, indicating that the scanned QR code may not correspond to a genuine vaccine, and further investigation or action may be required.

8) The QR code validation algorithm also keeps a record of all the QR codes scanned by consumers, along with their validation results, as transactions on the blockchain. This creates a transparent and auditable history of QR code validations, ensuring accountability and traceability.

9) The algorithm continues to validate QR codes scanned by consumers in real-time, ensuring that only authentic vaccines are verified and consumed by consumers, thereby preventing the use of counterfeit vaccines.

10) In case of any updates or changes to the vaccine tracking data in the blockchain, such as a new batch of vaccines being added or expired vaccines being removed, the QR code validation algorithm updates its reference data accordingly to ensure accurate validation results.

Overall, the QR Code Validation Algorithm in the Vaccine Tracker system validates the authenticity of QR codes scanned by consumers by checking the QR code data against the information stored in the blockchain, using cryptographic techniques to ensure data integrity and authenticity. This helps in verifying genuine vaccines and preventing the use of counterfeit vaccines by consumers.

C. Data Validation Algorithm

1) The Data Validation Algorithm constantly monitors the vaccine tracking data stored on the Ethereum blockchain to ensure data integrity and authenticity.

2) The algorithm retrieves the vaccine tracking data from the blockchain, including information such as vaccine batch numbers, manufacturing dates, shipment details, and other relevant data.

3) The algorithm verifies the integrity of the data by using cryptographic hashing techniques, where the data is hashed using a predefined hashing algorithm to generate a unique hash value.

4) The algorithm compares the computed hash value with the hash value of the data stored in the blockchain for the same data. If the hash values match, it indicates that the data has not been tampered with and is intact.

5) The algorithm also uses digital signatures to validate the authenticity of the data. Digital signatures used for this are generated using private keys and can be verified using corresponding public keys. The algorithm verifies the digital signatures associated with the vaccine tracking data using the public keys stored in the blockchain.

6) The algorithm checks if the data inside in the blockchain adheres to predefined rules and formats, such as checking if the batch numbers follow a certain pattern, manufacturing dates fall within expected ranges, and other validation checks specific to the vaccine supply chain.

7) The algorithm validates the authenticity of the data by verifying the cryptographic keys associated with the data. It ensures that the digital signatures match the corresponding public keys stored in the blockchain, indicating that the data has

been signed by authorized entities and has not been tampered with.

8) If the data passes all the validation checks, the algorithm confirms the integrity and authenticity of the data and provides a validation result indicating that the data is valid.

9) If any discrepancy or inconsistency is detected during the validation process, the algorithm raises an alert or notification, indicating that the data may have been replaced with or does not adhere to predefined rules.

10) The Data Validation Algorithm continuously monitors the vaccine tracking data on the blockchain, ensuring that the data remains tamper-proof and authentic throughout the supply chain process.

11) In case of any updates or changes to the vaccine tracking data in the blockchain, the Data Validation Algorithm revalidates the data based on the updated information and ensures that the updated data adheres to the predefined rules and cryptographic validation checks.

Overall, the Data Validation Algorithm in the Vaccine Tracker system ensures the combination and authenticity of the vaccine tracking data stored on the blockchain by using cryptographic techniques, such as hashing and digital signatures, and validating the data against predefined rules and formats. This helps in maintaining the trust and reliability of the vaccine tracking system and preventing any tampering or manipulation of the data stored on the blockchain.

V. Discussion

A. Transparency and Efficiency in Vaccine Supply Chains

The use of blockchain and AI algorithms in the Vaccine Tracker system can enhance transparency and efficiency in vaccine supply chains. Real-time location tracking using GPS or other technologies allows for accurate monitoring of vaccine movements, minimizing delays and identifying potential issues. QR code validation ensures the authenticity of vaccines, preventing the use of counterfeit vaccines. Data validation using cryptographic techniques ensures data integrity and authenticity, enhancing trust in the system.

B. Advantages of Location Tracking Algorithm

The location tracking algorithm used in the Vaccine Tracker system offers several advantages. It enables real-time tracking of vaccines at each stage of the supply chain, providing complete visibility and allowing for timely actions. However, challenges such as reliance on location tracking technologies, limitations in certain environments, and potential security concerns need to be addressed during implementation.

C. Robustness of QR Code Validation Algorithm

The QR code validation algorithm in the Vaccine Tracker system provides a robust method for authenticating vaccines. By verifying QR code data against blockchain-stored information, it ensures that consumers are scanning genuine QR codes associated with authentic vaccines. This helps protect consumer safety, maintain the integrity of the vaccination process, and prevent the use of counterfeit vaccines. However, interoperability with existing QR code standards and potential issues with QR code readability need to be addressed.

D. Data Validation Algorithm for Ensuring Integrity and Authenticity

The data validation algorithm used in the Vaccine Tracker system plays a crucial role in ensuring the integrity and authenticity of vaccine tracking data stored on the blockchain. By using cryptographic techniques, it validates data against predefined rules and verifies authenticity using cryptographic keys. This ensures that the data stored on the blockchain is tamper-proof and can be trusted. However, proper key management practices, potential security risks, and scalability of the algorithm need to be carefully evaluated and addressed.

E. Challenges

There are many challenges and limitations to consider in the usage of the Vaccine Tracker system. These include reliance on location tracking technologies, interoperability with existing systems, user adoption and acceptance, scalability during high-demand scenarios, and cost-effectiveness. Additionally, potential security risks associated with cryptographic keys, QR code readability issues, and adherence to industry standards should be considered during implementation.

VI. Experimental Results

A. Manufacturer Adding New Vaccine Batch

In this scenario, the Vaccine Tracker system is tested by simulating the addition of a new vaccine batch by a manufacturer. Below Fig. 2 shows the process of manufacturer adding new vaccine batch.

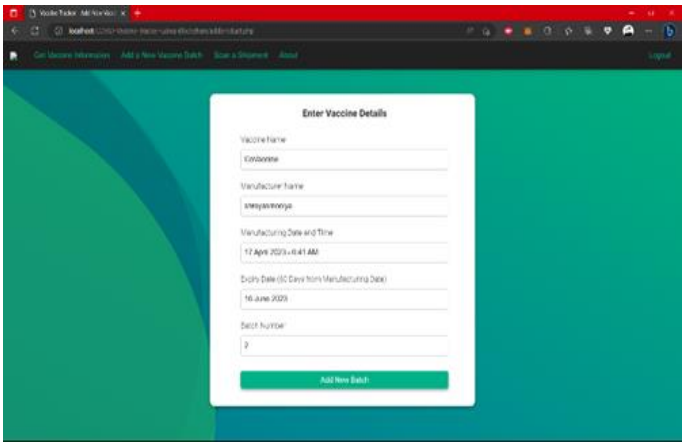

Fig. 2. Adding vaccine batch.

The experimental results may include the following:

- Successful addition of a new vaccine batch to the blockchain, including batch number, manufacturing date, expiration date, and other relevant information.
- Real-time recording of the batch information on the blockchain, ensuring transparency and immutability.
- Verification of the data validation algorithm, which ensures the combination and authenticity of the data stored on the blockchain.
- Validation of the QR code validation algorithm, which verifies the authenticity of the QR codes associated with the new vaccine batch.

- Successful integration of the location tracking algorithm, which tracks the movement of the vaccine batch using GPS or other location tracking technologies.
- Proper encryption and storage of location data on the blockchain, ensuring data privacy and security.

B. Organizations Viewing Vaccine Information and Scanning Shipment

In this scenario, the Vaccine Tracker system is tested by simulating the viewing of vaccine information and scanning of a shipment by organizations involved in vaccine supply chain. Fig. 3 shows vaccine shipment process.

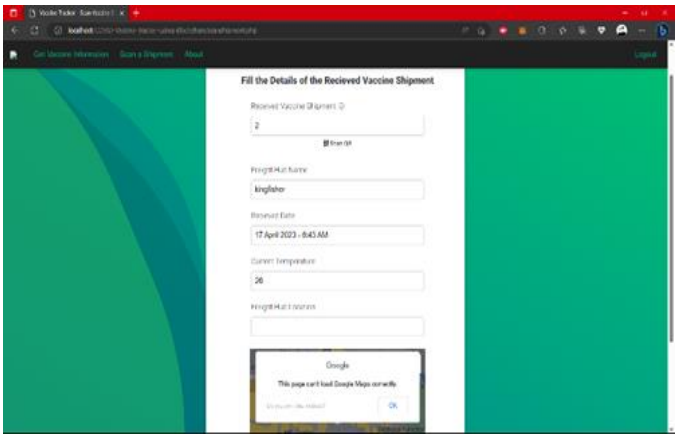

Fig. 3. Vaccine shipment.

The experimental results may include the following:

- Successful viewing of vaccine information, including batch number, manufacturing date, expiration date, location data, and QR codes, by relevant organizations such as distributors, healthcare providers, and regulatory authorities.
- Real-time tracking of the vaccine shipment using the location tracking algorithm, which provides accurate and on-date information on shipment's whereabouts.
- Validation of QR code validation algorithm, which verifies the authenticity of the scanned QR codes against the blockchain-stored information.
- Verification of the data validation algorithm, which ensures the combination and authenticity of the vaccine tracking data stored on the blockchain.
- Detection of any discrepancies or inconsistencies in the vaccine information, which may indicate potential issues such as counterfeit vaccines or supply chain disruptions.
- Proper access controls and permissions management, ensuring that only authorized companies can view and scan vaccine information.

C. Consumer Getting Vaccine Information

In this scenario, the Vaccine Tracker system is tested by simulating the retrieval of vaccine information by a consumer using QR code scanning. Below Fig. 4 shows how consumer can get vaccine information.

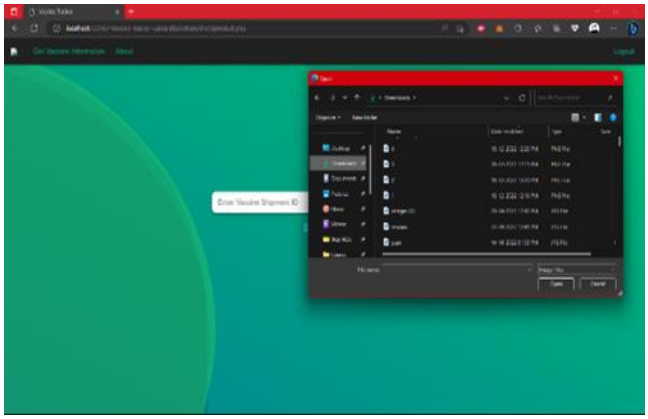

Fig. 4. Consumer page.

The experimental results may include the following:

- Successful scanning of the QR code on a vaccine package by a consumer using a smartphone or other QR code scanning devices.
- Retrieval of vaccine information, such as number, manufacturing date, expiration date, and location data, from the blockchain.
- Verification of the authenticity of the scanned QR code using the QR code validation algorithm, which ensures that the consumer is scanning a genuine QR code associated with an authentic vaccine.
- Provision of accurate and reliable vaccine information to the consumer, promoting security and trust in the vaccination process.
- Proper encryption and storage of consumer data, ensuring data privacy and security.

D. Tracking Log of Vaccine

In this part, the results of our blockchain-based vaccine tracking system, which enables end-to-end tracking of COVID-19 vaccines from the manufacturer to the consumer, with real-time updates displayed in Google Maps. Fig. 5 depicts the tracking of vaccine from source to destination.

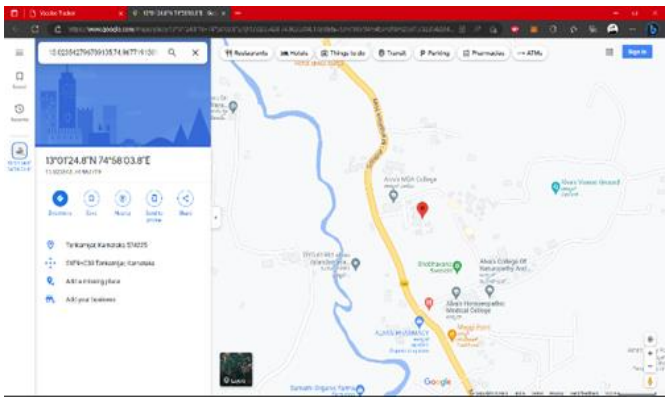

Fig. 5. Track record.

VII. Conclusion and Future Work

The Vaccine Tracker system, leveraging blockchain technology and AI-based algorithms, offers a robust and transparent solution for tracking and validating vaccine movements in the supply chain. The system provides real-time tracking of vaccines, validates the authenticity of QR codes, and ensures the integrity and authenticity of vaccine tracking data stored on the blockchain. The experimental results from testing and validation scenarios, including manufacturer adding new vaccine batch, organizations viewing vaccine information and scanning shipment, and consumer getting vaccine information, demonstrate the effectiveness and potential of the system in improving vaccine supply chain management.

The implementation of the Vaccine Tracker system has many key benefits, including enhanced transparency, traceability, and accountability in the vaccine supply chain. The system enables stakeholders, including manufacturers, distributors, healthcare providers, regulatory authorities, and consumers, to access accurate and reliable vaccine information in real-time, ensuring the authenticity and integrity of vaccines. The use of cryptographic techniques, such as hashing and digital signatures, ensures data security and privacy, protecting against data tampering and unauthorized access.

However, it's required to note that the success of the Vaccine Tracker system also relies on taking and collaboration of various stakeholders in the vaccine supply chain, as well as adherence to relevant regulations and standards. Further research and development can be explored to optimize the system's performance, scalability, and interoperability with existing vaccine supply chain management systems.

In conclusion, the Vaccine Tracker system has the potential to significantly improve vaccine supply chain management by leveraging blockchain technology and AI-based algorithms. The system's transparency, traceability, and data validation capabilities can enhance the trust and efficiency of vaccine distribution, ensuring that safe and authentic vaccines reach the end consumers. With proper implementation, the Vaccine Tracker system can contribute to the global efforts in ensuring the availability and safety of vaccines, ultimately benefiting public health worldwide. In the future work, we can improve the proposed system using artificial intelligence (AI) and deep learning techniques, for even further advancement, our suggested method can use a hybrid machine learning approach.

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