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*Original research article*

# Covid-19 Antigen Test Kit Distribution System Based-on Blockchain Technology

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**ABSTRACT**

Transparency is the primary component of developing trust to ensure the integrity of the supply chain. Each business must provide information and contribute to its supply chain. One of the many products that have been brought out during the pandemic is COVID-19 ATK (Antigen Test Kits) which must be used almost constantly in many situations. In recent years a technology known as blockchain attracted the attention of many individuals. Blockchain is an advanced database mechanism that allocates data within a decentralized system. This paper explores the efficiency of blockchain technology in enhancing supply chain transparency to ensure the quantity of COVID-19 ATK and to simplify the supply chain management experience by using Web 3.0. The proposed system uses smart contracts to record the transaction since the product has been manufactured and transferred across the supply chain network. The customer can ensure the integrity of the product by entering the product's details, lot id, and expiration date, into the blockchain system to query the supply chain history. The system can detect many abnormalities, such as counterfeit, modified, and smuggled products.

**Keywords:** Blockchain; Covid-19 ATK; Smart contract; Supply chain management; Web 3.0

## 1. Introduction

The recent COVID-19 pandemic has had a disruptive impact on the global economy and GDP, with estimations by G. Gopinath [1] from the International Monetary Fund suggesting a potential loss of over $22 trillion between 2020 and 2025. This economic downturn has also influenced international supply chain management, impeding economic recovery. One of the notable products that emerged during the pandemic is the COVID-19 ATK, which is extensively utilized in various scenarios.

Counterfeit or unauthorized Covid-19 antigen test kits have emerged as a pervasive global issue with widespread implications. The U.S. Food and Drug Administration (FDA) has issued a formal caution to the public regarding the increasing prevalence of unauthorized at-home testing kits. The FDA noted that using an unauthorized diagnostic carries a heightened risk of receiving false

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results from counterfeit tests, which could in turn lead to the needless spread of the coronavirus if proper safety protocols aren't followed [2].

Furthermore, it is imperative to acknowledge that the performance and reliability of these spurious tests remain inadequately validated, causing significant concern to the FDA. By employing unauthorized testing kits, individuals inadvertently assume the risk of unwittingly perpetuating the spread of COVID-19. Moreover, reliance on counterfeit tests may lead to delays or cessation of appropriate medical intervention for COVID-19. While hundreds of FDA-approved Covid test kits are currently available to consumers, there are also hundreds of fakes [3]. There is a compelling need for a platform capable of effectively managing and overseeing the Covid-19 antigen test kit supply chain.

In recent years, blockchain technology has garnered considerable attention. It serves as an advanced database mechanism that operates within a decentralized system. Blockchain stores data in the form of securely interconnected blocks, employing cryptography. Participants in the system can establish a node, which functions as a server contributing to the network. Public key cryptography is utilized to identify users on the blockchain network, generating a shared public key accessible to all network participants, as well as a private key unique to each member. These keys serve as references for verification and facilitate access to the ledger's data. Additionally, blockchain incorporates smart contracts, which are self-executing agreements stored within the blockchain. These contracts automatically execute predefined actions when specific conditions are met. Implementing blockchain technology enhances the ability to trace, secure, establish trust, and maintain transparency in data exchanged across the network. It proves to be highly effective in document validation, asset ownership, and supply chain management.

In response to the challenges posed by the pandemic, various technological solutions have been explored to streamline supply chain processes and enhance transparency. Blockchain technology, with its decentralized and secure nature, has attracted considerable attention as a potential enabler of trust and traceability in supply chain operations. Blockchain has been successfully applied in healthcare, as exemplified by the work of DAPP for smart health [4], which proposed a decentralized application for managing patient data in a private chain, incorporating on-chain and off-chain data to ensure data integrity and privacy. The application of blockchain's cryptographic techniques in healthcare can be adapted for specific product transfers, including COVID-19 vaccines, ensuring secure and encrypted data exchange [5].

Furthermore, noteworthy contributions include the work of S. Tanwar [6], which demonstrates data allocation and elucidates the interactions of different roles with the blockchain for data entry and access. L. Ismail [7] illustrates the connectivity of nodes and their responsibilities in transferring information among themselves. Finally, J. H. Tseng [8] showcases the transfer and tracking of products across the supply chain through the implementation of blockchain technology. These studies provide relevant insights to inform the present paper.

This work has made a significant contribution by furnishing a platform for the verification of the Covid-19 antigen test kit supply chain and the identification of counterfeit test kits. The foundational design of this system involves the integration of blockchain technology for the seamless recording of data, commencing from the manufacturer and culminating at the customer's end. The core components of the supply chain, which can be authorized and approved by a middleman organization, are represented by their DUNS (Data Universal Numbering System) and tax ID numbers.

When a manufacturer produces a product, a ledger is created within the system to document its details, including the Lot ID, SKU (Stock Keeping Unit), manufacturer name, production date, quantity, and expiration date. This ledger serves as a reference point for subsequent transactions involving the product. Every transaction occurring within the system is recorded, encompassing buyer and seller information, as well as product details that can be traced back to previous transactions and ultimately to the origins of the supply chain. This system acts as a tracker, enabling customers to verify the integrity of the product by accessing its history through the blockchain system.

The study aims to investigate the capabilities of blockchain technology by developing a ledger-based tracking system for a website, replicating data input to simplify supply chain management. To accomplish this objective, a comprehensive research design is implemented, encompassing three main sections. Firstly, the Methods section provides a detailed description of the experimental approach, including system design and development, smart contracts, roles, use cases diagram, products, and anomaly detection. Subsequently, the Results section presents the user interface of the website and the algorithms used.

Finally, the Conclusion section summarizes the key findings, discusses associated challenges, and proposes potential avenues for future research.

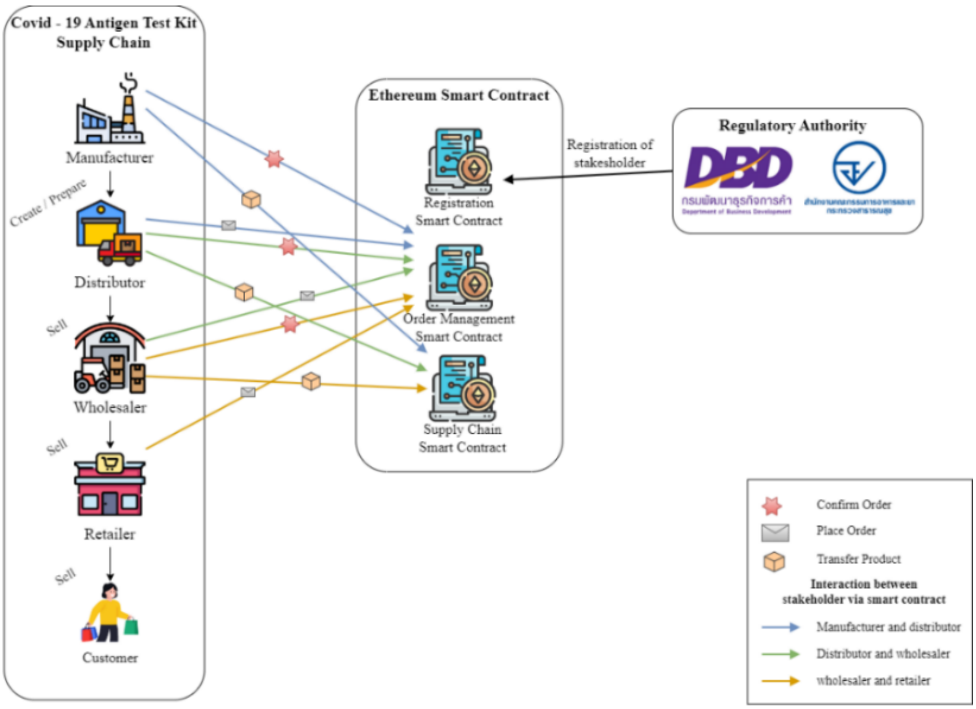


**Fig. 1.** System architecture overview.

## 2. Materials and Methods

### 2.1 System architecture

The objective is to integrate blockchain technology into the supply chain of COVID-19 ATK. The supply chain comprises several participants, including manufacturers, distributors, wholesalers, retailers, and end customers. In this work, Solidity, a programming language for creating Smart Contracts on the Ethereum blockchain, was employed. The smart contracts were divided into three main components, each serving a specific purpose: user registration, product management, and order management. However, unlike [9] which proposed having a Regulatory Authority serve as a role inside the blockchain network, the website was designed to have an administrator responsible for its operations, typically an authoritative entity such as the Department of Business Development or the Food and Drug Administration (FDA). Fig. 1 provides an overview of the system architecture.

## 2.2 Web 3.0 application

In accordance with the chosen system architecture, we opted to develop Web 3.0, selecting the Ethereum blockchain as our preferred solution due to its widespread usage and the absence of any need of specific functionalities, as our primary objectives revolved around recording data on the blockchain and ensuring the privacy of ETH clients. The utilization of Ethereum offers a notable advantage, given its foundational capabilities that enhance scalability. It also proves particularly advantageous when speed in recording transactions into blocks and efficient scale loading of data are essential requirements. Subsequently, we constructed a Web 3.0 application designed to operate on the Ethereum platform, with Fig. 2 depicting the architecture of our Web 3.0 application.

Our Web 3.0 application consists of the following components:

2.1) The Browser is used to interact with the Web 3.0 application which is primary interface facilitating user interaction.

2.2) The Signer is a component for transactional operations within the Web 3.0 framework, used to sign transactions and authenticate the user. We decided to use MetaMask because it serves the dual role of a wallet and blockchain identification tool, ensuring secure data storage within transactions. This choice aligns with our objective of leveraging a versatile solution that seamlessly integrates with our system requirements.

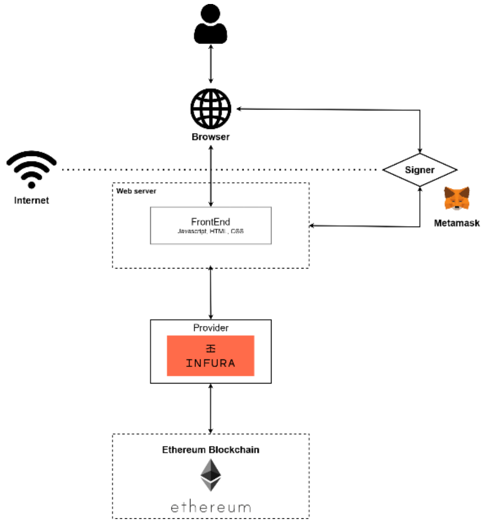

**Fig. 2.** Web 3.0 application architecture.

2.3) The Web server and Front-end are responsible for hosting the front-end code of the Web 3.0 application, encompassing HTML, CSS, and JavaScript components in this instance.

2.4) The Provider is a connection to the Ethereum blockchain. It is used to send and receive transactions. In our case, we opted to employ Infura, a development suite that furnishes immediate and scalable API accessibility to the Ethereum and IPFS networks, as our chosen provider.

2.5) Ethereum Blockchain is the underlying platform that powers Web3 applications.

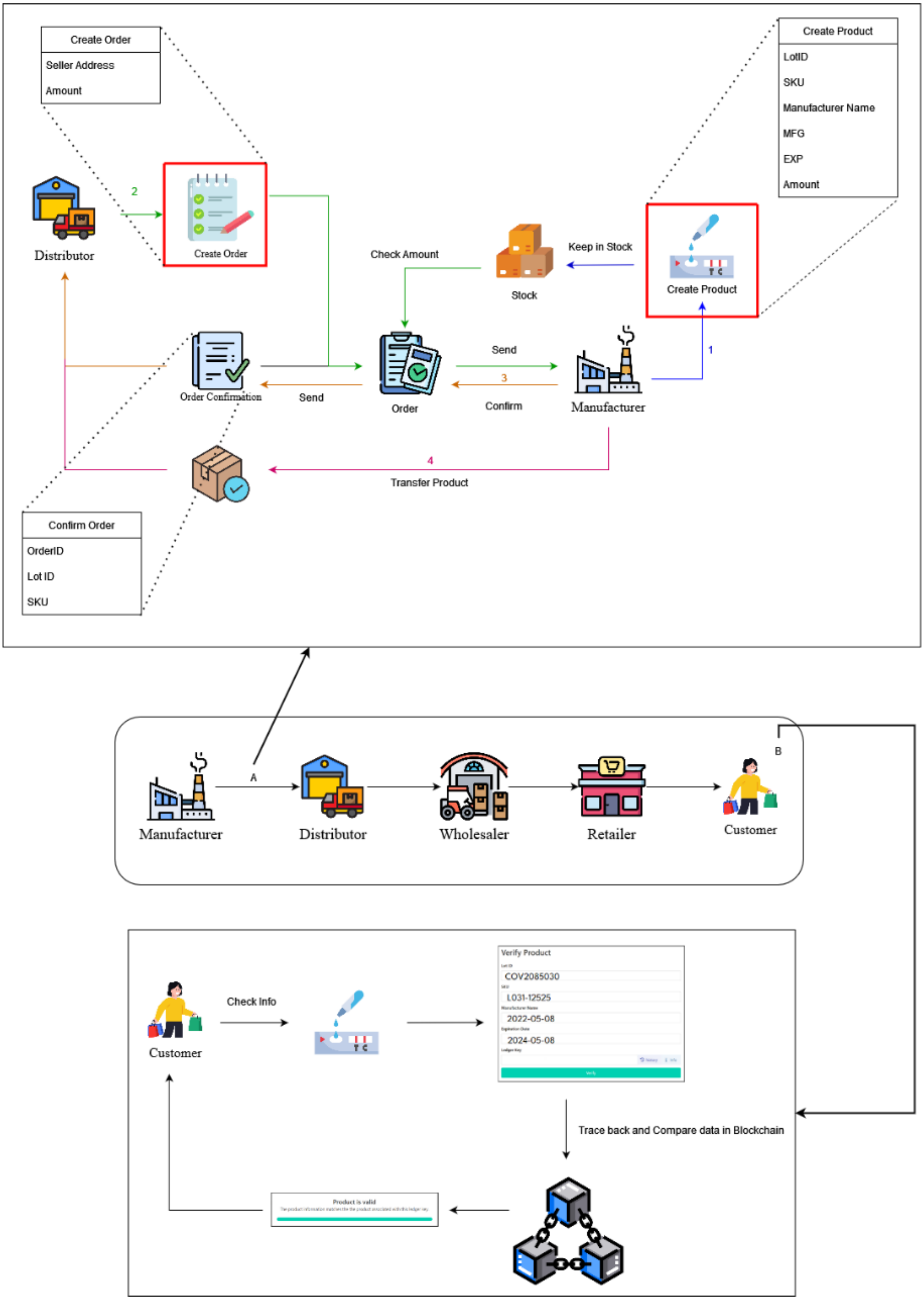


**Fig. 3.** Workflow diagram.

## 2.3 System Design

The system commences its workflow, as illustrated in Fig. 3. After users are added by the administrator, the users comprising the various components of the supply chain, including manufacturers, distributors, wholesalers, and retailers, assume the role of registered users on the blockchain platform. These participants are added by Registration smart contract from administrators who bear the responsibility for overseeing the operations of the blockchain. Notably, the administrators function as authoritative entities, such as the Department of Business Development or the Food and Drug Administration, as previously stated.

When a manufacturer creates a new product, the manufacturer logs into the website using their blockchain account, enters relevant information about the new product, and stores this product data in the blockchain by the utilization of smart contracts, which are programmable codes residing on a blockchain network and implemented using the Solidity programming language. These contracts are deployed on the blockchain, serving as immutable and transparent mechanisms for executing predefined actions and enforcing agreed-upon terms. In the present scenario, the Supply Chain smart contract has the responsibility of storing all relevant product information, as well as the tracking of product ownership for all users, including the current quantity held by each user which subsequently serves as a point of reference for the following stages in the process.

Subsequently, whenever a transaction involving the product takes place, all pertinent details, including product information, owner information, and buyer information, are recorded in the blockchain and monitored based on the status of that particular transaction. The participants comprising the various components of the supply chain, including manufacturers, distributors, wholesalers, and retailers, assume the role of registered users on the blockchain platform. These participants are added by Registration smart contract from administrators who bear the responsibility for overseeing the operations of the blockchain.

As the product traverses the supply chain through various transactions, this information is continually updated by an Order Management smart contract which records and monitors all transactions taking place, encompassing completed, processing, and canceled transactions. Finally, when the product reaches the end of the supply chain and is sold to customers, the customers can access the product information stored in the blockchain by using their purchased product to search for it within the blockchain system.

## 2.4 Smart contracts

This project utilizes three distinct smart contracts, which are software programs residing on the blockchain and designed to execute specific actions upon meeting predetermined conditions. These smart contracts serve crucial functions within the blockchain system:

2.1) The Registration smart contract governs access control, role administration, and the capability to add or remove users.

2.2) The Supply Chain smart contract is responsible for managing products, including the creation of new products, facilitating product transfers among users, and detecting any anomalies that may arise.

2.3) The Order Management smart contract facilitates the transfer of products between users and aids in monitoring the status of each transaction.

## 2.5 Roles

Within the blockchain system, each user is assigned a specific role that entails a defined set of responsibilities, as outlined in Table 1. The registration smart contracts are

**Table 1.** Roles Functionality.

| Functions / Roles | Admin | Manufacturer | Distributor | Wholesaler | Customer |
|---|---|---|---|---|---|
| addUser() | ✓ | | | | |
| deleteUser() | ✓ | | | | |
| createProduct() | ✓ | ✓ | | | |
| transferProduct() | | ✓ | ✓ | ✓ | |
| verifyProduct() | ✓ | ✓ | ✓ | ✓ | ✓ |

responsible for allocating roles to users, and the assigned roles are as follows:

#### *2.5.1 Administrator*

The administrator holds the responsibility of adding new users to the supply chain system and assigning them appropriate roles, such as Manufacturer, Distributor, Wholesaler, and Retailer. To ensure the integrity of the system, it is crucial to verify the credentials of new users before granting them access. The administrator also possesses the authority to cancel or remove existing accounts from the system, thereby ensuring its efficient and secure operation.

#### *2.5.2 Manufacturer*

The manufacturer account can create new products and sell them to distributors or wholesalers. Additionally, the manufacturer account has access to functions that are also available to other accounts within the system.

#### *2.5.3 Distributor, Wholesaler, and Retailer*

The primary responsibility of these accounts is to record product transactions and facilitate the transfer of ownership to the new owner.

### 2.6 Use cases diagram

The system's use cases diagram, depicted in Fig. 4, illustrates the interconnections between role functions and smart contracts, as previously mentioned. The four primary roles identified are admin, manufacturer, customer, and distributor/wholesaler/retailer. The admin role is responsible for the addition and removal of users within the registration smart contract. Manufacturers possess the ability to create products, which subsequently record product data on the blockchain. The creation and transfer of orders across the supply chain are functionalities shared by distributors, wholesalers, and retailers. Lastly, the product verification function is accessible to all users, including customers who may not have blockchain accounts registered on the website.

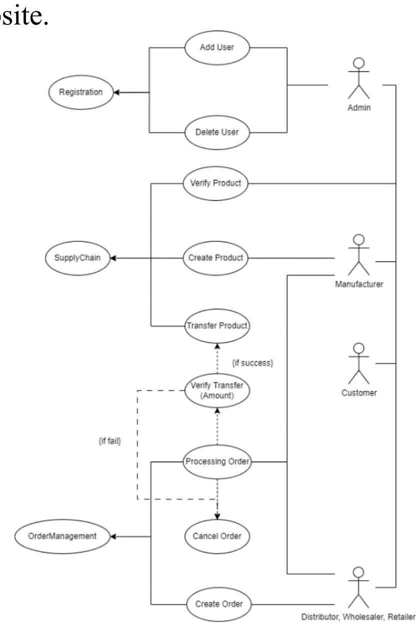


**Fig. 4.** System use cases diagram.

### 2.7 Product

The following information outlines the specific product details that are recorded on the blockchain and serve as points of reference.

#### *2.7.1 Lot ID*

This is a distinctive identification number assigned to a particular quantity or batch of material that originates from a single manufacturer.

#### *2.7.2 SKU (Stock-Keeping Unit)*

The SKU is utilized for product categorization and serves the purpose of tracking items within a warehouse.

#### *2.7.3 Manufacturer name*

This refers to the name of the manufacturer responsible for producing the item.

#### *2.7.4 Manufacturing date*

The manufacturing date signifies the specific day on which the product was produced.

#### *2.7.5 Expiration date*

The expiration date is a pre-established date indicating when the product should no longer be used or consumed.

## 3. Results and Discussion

Blockchain technology enables the storage of data while ensuring its integrity. The implementation of a ledger-based tracking system on the website streamlines the management of the supply chain. Blockchain also plays a role in resolving issues related to asset ownership through ledger authentication. However, the practical application of blockchain technology is contingent upon external factors such as the collaboration of supply chain personnel, the management of gas costs, and the usability of the software. Integrating these technologies into an organization's existing supply chain operations necessitates time and organizational restructuring. When a user needs to be authorized within a blockchain system, the involvement of an intermediary becomes necessary to oversee user activities and identify anomalies to ensure the system's integrity. The prototype homepage of this work is shown in Fig. 5.

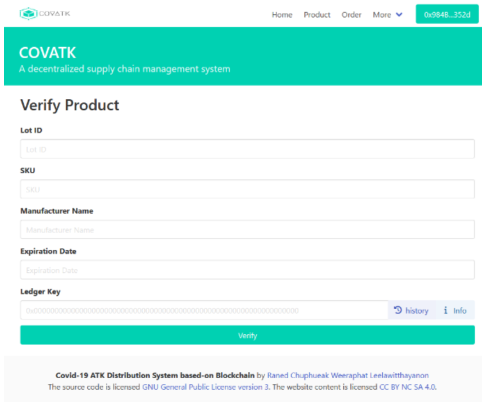


**Fig. 5.** The prototype Homepage.

### 3.1 Interface

The user interface comprises four primary pages, each serving a specific purpose.

#### *3.1.1 User registration page*

This page is dedicated to the administrator, who is responsible for adding new users to the system and overseeing its maintenance.

#### *3.1.2 Product verification page*

Users can utilize this page to verify the authenticity and details of a product.

#### *3.1.3 Product page*

This page allows users to add or check the products in their possession, providing a comprehensive view of their product inventory.

#### *3.1.4 Order Management page*

The purpose of this page is to monitor and track the status of orders and transactions.

The product verification page serves as the homepage as it allows access to this function for individuals who are not yet registered in the system. This includes customers who can utilize this function to verify products. More detailed information regarding the product verification process will be provided later in this section.

### 3.2 User registration

Access to this page is restricted to the administrator, who bears the responsibility of adding new users and ensuring the system's maintenance. The website incorporates the utilization of the DUNS number or tax number for user authentication, reflecting the corresponding real-world corporation. Each corporation is assigned roles such as manufacturer, distributor, wholesaler, and retailer based on their respective functions. The user's blockchain address serves as a unique identifier and is essential for accessing the system. Additionally, the user's name and email are recorded for reference purposes. The user registration page as shown in Fig. 6.

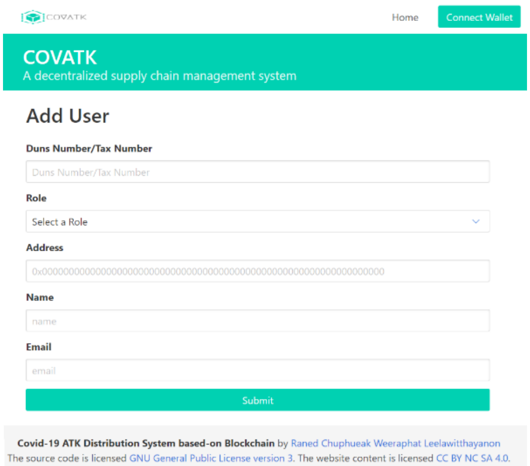


**Fig. 6.** User registration page.

### 3.3 Order management

The order management page is exclusively accessible to verified users. It encompasses three main sections that facilitate efficient order tracking. The first section, labeled "Ongoing Orders", pertains to orders that are currently awaiting partner confirmation. The second section, titled "Shipping Orders", pertains to orders that are in the process of being delivered. Lastly, the "Finished Orders" section encompasses completed or canceled orders. This page serves as a centralized hub for users to monitor the progress of their orders, including transaction status and related details.

The script embedded within the order management smart contract can be accessed through the order management page, as illustrated in Fig. 7. Once a verified user has successfully logged into the system, they can create transactions and enter the blockchain address of the desired trading partner to initiate the transaction. All these transactions are effectively processed within the confines of this webpage.

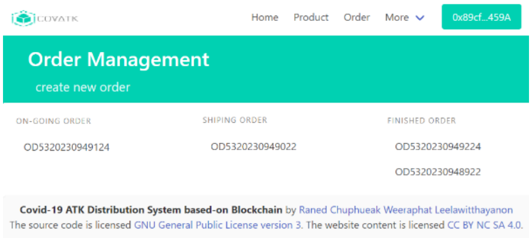


**Fig. 7.** Order management.

The transaction processing system exemplifies a four-step process. The process commences with the buyer initiating a request to the product owner, specifying the desired quantity of the product. The product owner reviews the request details and is then required to decide whether to confirm or accept the order for further processing. Once the order has been approved, the product owner proceeds to ship the item to the buyer. Upon receiving the item, the buyer inspects it and confirms the transaction back to the product owner. The completion of all the steps signifies the finalization of the transaction, which is then recorded and logged in the system as shown in Fig. 8.

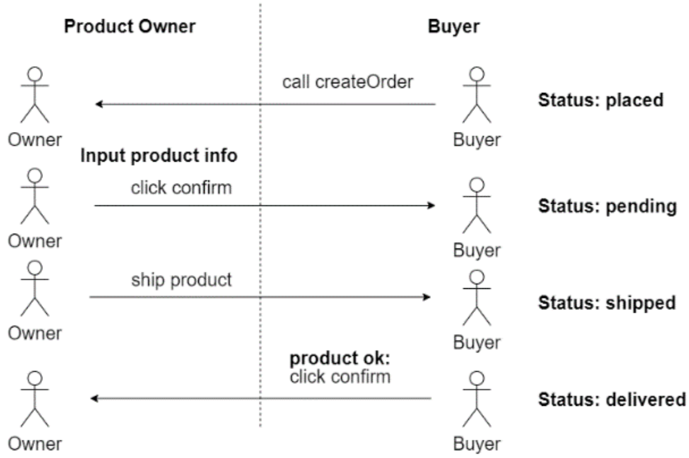


**Fig. 8.** Example of transaction processing system.

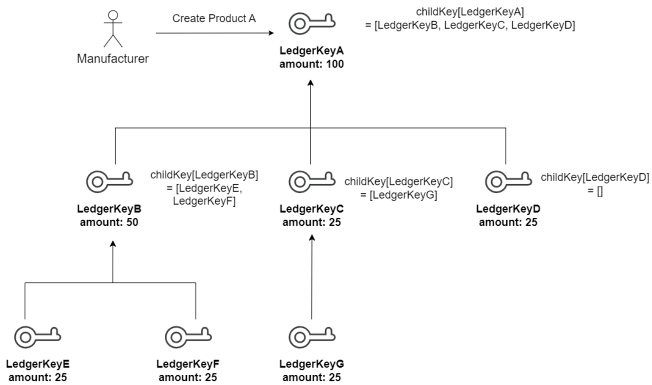


**Fig. 9.** Transaction variable allocation.

**3.4 History**

Illustrated in Fig. 9, the transaction variable allocation exemplifies the capability of product owners to verify the historical chain of ownership by inspecting the previous owner's address on the history page. This verification process is facilitated through the utilization of the “Ledger Key” variable within the algorithm. When a manufacturer creates a product, a ledger key is generated using a hash algorithm. Similarly, after the completion of a transaction involving the product, a corresponding ledger key referencing that specific transaction is also generated. Each transaction includes a list of child keys that serve as pointers to reference the preceding transaction in the chain.

Through the input of the product's details and the associated ledger key, the system effectively utilizes the provided ledger key to trace back to the initial transaction when the product was manufactured by the corresponding manufacturer. This procedure enables the verification of the product's identification. This process is illustrated in the history verification depicted in Fig. 10.

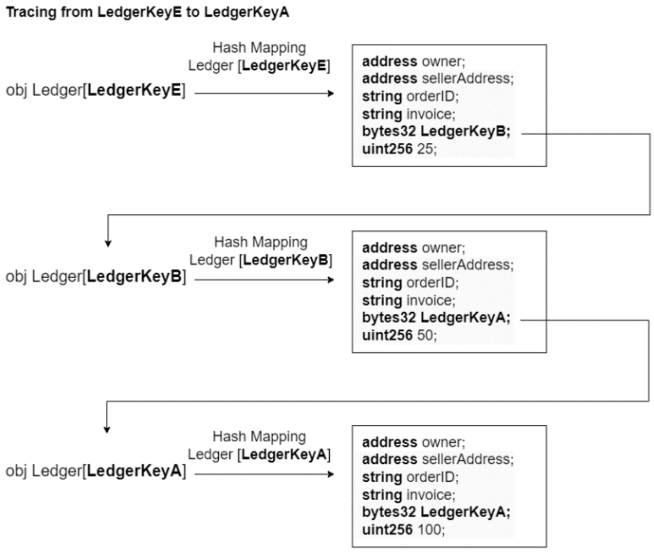


**Fig. 10.** History verification.

### 3.5 Verify product

This function allows for the verification of a product by inputting its details and comparing them with the stored product data in the system. Upon matching the client-entered data with the product information stored in the system, the product is deemed authentic, and the verification process is deemed successful.

This function operates by utilizing the user function, which can represent a customer making a purchase or any other type of user within the blockchain system. The user inputs the product information along with the most recent transaction ledger key. The system then takes this ledger key and cross-references it with the previous transactions involving the specified product. This iterative process continues until reaching the initial transaction, where the manufacturer created the product and entered its information into the blockchain system, as depicted in Fig. 10. By following this approach, the function ensures that the product's origin and all previously recorded transactions remain consistent, thereby verifying the authenticity of the product in the possession of the customer. However, if the system fails to locate the previously completed transaction or the product information stored in the blockchain, the product fails to pass validation. It is worth noting that this function is accessible to all, including unregistered individuals such as customers. The verifying product algorithm is depicted in Fig. 11, while the verifying product result is illustrated in Fig. 12.

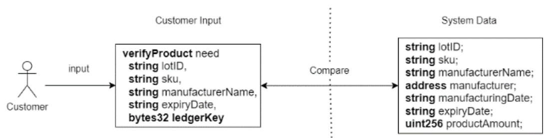


**Fig. 11.** Verify product algorithm.

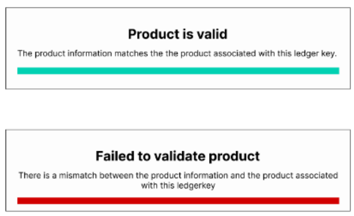


**Fig. 12.** Verify product result.

**Table 2.** System Anomalies.

| Anomalies | Description |
|---|---|
| Primary data discrepancies | This anomaly occurs when a user enters specific product information into the system, and the system verifies whether the provided information matches the recorded data in the system. |
| Unregistered items entering the supply chain | If an item owned by a user is not registered in the system, there will be no product data stored for that item. |
| User spoofing | Each user in the system has unique role functionality. If a user is not validated, they will not be able to perform any system functions. |
| Exceeding the amount of product | Users can verify a product's details using the system's recorded data to determine the number of units manufactured. |
| Exceeding amount transfer | When a transaction takes place within the system, the system automatically detects if the transferred amount exceeds the user's current possession by tracing back to the previous transaction. In such cases, the transaction is automatically reversed. |

### 3.6 Anomaly detection

The identification of fraudulent activities within the system involves three distinct categories of conflicts. Firstly, data conflicts arise when the input data does not correspond with the stored data in the system. Secondly, amount conflicts occur when the quantity of products does not align with the quantity recorded for a particular user. Lastly, conflicts relating to users can be effectively identified through the implementation of a blockchain system.

The proposed blockchain-based system can detect product fraud within the system through the mechanisms outlined in Table 2 presented.

### 3.7 Advantages and disadvantages

The advantages of Covid-19 antigen test kit supply chain are as follows:

#### *3.7.1 Immutability*

Blockchain technology ensures that once data is recorded, it becomes practically impossible to alter or manipulate, enhancing data integrity and trust.

#### *3.7.2 Traceability*

The ability to trace a product's journey from manufacturers to the end-user through blockchain addresses provides an effective means to identify and mitigate counterfeits and maintain a transparent supply chain.

#### *3.7.3 Fraud detection*

The incorporation of five distinct anomaly detection mechanisms contributes to effective fraud detection, enhancing the overall security of the supply chain.

The disadvantages are as follows:

#### *3.7.4 Complexity*

Implementing and managing a blockchain-based supply chain can be intricate, particularly for stakeholders who are not well-versed in blockchain technology. It may require additional training and resources to ensure smooth operations.

#### *3.7.5 Cost*

The initial setup costs and ongoing transaction fees associated with blockchain adoption can be relatively high, potentially posing a financial burden for businesses looking to implement blockchain solutions. It's crucial to weigh the benefits against these costs when considering adoption.

## 4. Conclusion

This endeavor has made a significant contribution by furnishing a platform for the verification of the Covid-19 antigen test kit supply chain and the identification of counterfeit test kits. The foundational design of this system involves the integration of blockchain technology for the seamless recording of data, commencing from the manufacturer and culminating at the customer's end. Our initiative is to establish a unifying framework, facilitating the participation of a global consortium encompassing manufacturers, distributors, wholesalers, retailers, and end-users within the same network.

Our prototype deployed on the Sepolia testnet successfully operated for its intended purpose. The smart contracts were categorized into three primary components and assigned to different sections, namely user registration, product management, and order management. Notably, the order management component was capable of detecting five types of anomalies, including primary data discrepancies, unregistered items entering the supply chain, user spoofing, exceeding the number of products, and exceeding amount transfer.

The implementation process involved the use of several libraries, which necessitated additional time investment to gain proficiency in these tools. Through this process, it became evident that blockchain technology can be effectively utilized as intended and can securely store data while ensuring integrity. However, certain implementation challenges remain, such as the need for careful resource management to avoid excessive usage and the necessity for a meticulous system design to prevent errors that may compromise the system's functionality during user onboarding. Additionally, the supervision of users and transactions by an authorized entity is crucial. To address concerns regarding product transportation and establish trust in this aspect, modifications to the implementation system are required. Collaboration from all stakeholders is essential for the success of this initiative, which has the potential to expand nationally and integrate with other IoT devices.

Specifically, enhancing the security of product transportation, both externally and internally, and addressing the issue of high gas fees associated with transactions. Gas fees are incurred as transaction fees within the blockchain system, necessitating adjustments in the variable allocation of smart contracts. Ethereum 2.0 has been developed with the primary objective of addressing performance issues and reducing transaction fees, which have been concerns in the earlier versions of the Ethereum blockchain. Moreover, as blockchain technology is still relatively new and prone to instability, continuous monitoring is essential. Furthermore, the incorporation of IoT devices, as proposed by [10], could significantly augment the effectiveness of our blockchain platform, especially when utilizing sensors that can independently update information on the blockchain. This integration may also lead to the expansion of systems incorporating both on-chain and off-chain data, along with the classification of users based on applied payment contracts similar to [9]. Thorough system testing should be conducted before its practical implementation to ensure its security and effectiveness.

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