FarmersChain: IoT and Blockchain Based Farmer Centric Supply Chain Management System Based In India

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ARTICLE INFO

Keywords:
Blockchain
Smart Contracts
Supply Chain
Agriculture

ABSTRACT

The supply chain industry has grown more complex over the years due to globalisation. Blockchain, the underlying mechanism of Bitcoin, was introduced more than a decade ago. Blockchain is a decentralized distributed ledger technology. Blockchain consists of several immutable blocks that are connected and distributed over a network. Blocks store data, a cryptographic hash of the previous block and a timestamp. The blockchain is distributed over a network which helps stop malicious transactions. Smart contracts are like real-world contracts but written as a piece of code. Ethereum, an open-source blockchain-based software platform supports smart contracts. When smart contracts are deployed on a blockchain, for example, Ethereum, they are self-executing. Whenever a transaction occurs, the smart contracts are immediately applied to them without a third party executing it.

This paper proposes a farmer-centric agricultural supply chain system that uses IoT (smart sensors), smart contracts and blockchain. This paper aims to address the challenges that exist in the current supply chain i.e., accountability and traceability of the product. This paper proposes to use IoT devices like smart sensors to provide real-time data of the product it is attached to, smart contracts to automate the supply chain process to agreed terms and the blockchain to store all this data in a decentralised database. This ensures traceability of the product throughout the supply chain making everyone involved accountable.

1. INTRODUCTION

Food is central to people's lives and human communities all over the world. The food and agriculture industry is considered a major employer around the world. This massive industry is composed of various partners from various sectors like farmers (producers), wholesalers, distributors, consumers, etc., which renders this industry as one of the most complicated and difficult supply chain systems. Agriculture is dependent on various factors like weather, quality of seeds, method of farming, moisture, humidity, soil type, etc., which are variable which makes monitoring the quality of produce difficult and complex without a proper management system.

India is an agrarian country, agriculture in India contributed to 18% of its GDP and provided employment to 42% of its population in 2020. India is also one of the major producers of the world. India’s exports touched Rs. 2.52 lakh crores in the financial year 2019-2020. Even though India’s agricultural sector is one of the largest in the world, it faces problems with supply chain issues like traceability of the produce, fair prices to both the farmers and the consumers.

The primary goal of this research work is to implement a smart contract that can provide traceability of the product (or produce) throughout the supply chain from the farmer to the consumer by using a blockchain. This study contributes to the ongoing global research in smart contracts and blockchain to better understand, explain, and provide transparency, accountability and traceability of the agricultural supply chain management system.

1.1. WHAT IS A BLOCKCHAIN?

The idea of blockchain has been around since 1982 when cryptographer Davic Canum proposed a protocol in his dissertation “Computer Systems Established, Maintained, and Trusted by Mutually Suspicious Groups” [1]. In 1991, Stuart Haber and W. Scott Stornetta published an article on “How to time-stamp a digital document” [2], where they “propose computationally practical procedures for digital time-stamping of such documents so that it is infeasible for a user either to back-date or to forward-date his document, even with the collusion of a time-stamping service” [2]. But it is not until 2008 that the first blockchain was conceptualised by an anonymous person or a group of people called Satoshi Nakamoto. Satoshi Nakamoto released a paper in 2009 called “Bitcoin: A Peer-to-Peer Electronic Cash System” [3] where they discussed a peer-to-peer version of electronic money that would allow online transactions between pirates without going through a financial institution and without the problem of double-spending.

According to IBM, “Blockchain is a shared, immutable ledger that facilitates the process of recording transactions and tracking assets in a business network. An asset can be tangible (a house, car, cash, land) or intangible (intellectual property, patents, copyrights, branding).” [4]. In a basic way, the blockchain is a decentralised, distributed ledger, which uses a peer-to-peer network. The ledger consists of immutable blocks that are linked to each other. Each block has a cryptographic hash of the previous block, a timestamp, and the transaction data. The ledger is duplicated and distributed across the entire network of systems (or nodes) on the blockchain.

1.2. WORKING OF BLOCKCHAIN

Blockchain works on the basis of a distributed ledger technology (DLT), where the data is recorded digitally and is stored in multiple geographical locations [5]. A DLT is decentralized. The basic operation of the blockchain can be broken down into the following steps:

- A transaction on the blockchain network is made.
- The transaction between the parties is verified by other systems (or nodes) on the blockchain network.
- If the transaction is verified, the transaction data is added to a block to get hashed.
- Once the hashing is complete and the block is created, it is added to the blockchain.

There are two types of blockchains, public blockchains where the blockchain is decentralized and does not have a single entity which controls the network like, and private blockchain which works based on access controls which restrict the people who can participate in the network. Ethereum is a good example of a public blockchain. Hyperledger Fabric is a good example of a private blockchain.

This article [6] lists the properties or features of a blockchain:

- The blockchain is **distributed**, all the nodes on the network will have a complete copy of the ledger for transparency.
- The blockchain is **immutable**, any validated blocks on the blockchain are irreversible and can not be changed.
- The blockchain is **time-stamped**, a time-stamp is given to every block that is added to the blockchain.
- The blockchain is **unanimous**, for a transaction to be validated and added to the blockchain, all the participants of the network (systems or nodes) must unanimously agree to it.
- The blockchain is **programmable**, smart contracts can be added to a blockchain.
- The blockchain is **secure**, all the data that is entered into a block is encrypted.

1.3. WHAT ARE SMART CONTRACTS?

Nick Szabo coined the term "smart contracts" in the 1990s, referring to it as “a set of promises, specified in digital form, including protocols within which the parties perform on these promises” [7]. As discussed in this article [8], a smart contract is an agreement between the parties on a blockchain, who are for example transferring funds between each other.

A smart contract is a part of the blockchain which means it has the same properties (or features) as the blocks on the blockchain. A smart contract is also self-executing, once it is put on the blockchain, whenever a transaction occurs on the blockchain the smart contract is automatically executed as all the systems (or nodes) on the network have a copy of the contract on them.

Smart contracts share similar characteristics with the Ricardian Contract, Grigg the author of the paper saw Ricardian Contracts as a bridge between text contracts and code that had the following parameters: a single document that "is a) a contract offered by an issuer to holders, b) for a valuable right held by holders, and managed by the issuer, c) easily readable by people (like a contract on paper), d) readable by programs (parsable like a database), e) digitally signed, f) carries the keys and server information, and g) allied with a unique and secure identifier." [8][9]

1.4. WORKING OF SMART CONTRACTS

Ethereum is a very popular decentralised open-source blockchain platform with smart contract functionality. To understand the working of smart contracts on a blockchain, we need to understand Ethereum and how it works. The account is the basic unit of Ethereum, and the Ethereum blockchain keeps track of each and every account. Any time there is a value or information exchange between accounts, the state transformations of the accounts are recorded on the blockchain. There are two types of accounts on Ethereum: Externally Owned Accounts (EOAs) and Contract Accounts. EOAs are controlled by private keys that are assigned to human users,
whereas Contract Accounts are governed by their internal code and can only be activated by an EOA [10][11]. Contract Accounts are where smart contracts reside within the blockchain.

To build a smart contract, parties must first define a collaborative incentive and agree on the desired results for each party. This could include any possible exchange of value such as goods or services. Following that, they must establish the terms and conditions that must be followed in order for an exchange to take place. These could be triggered by the parties themselves, by external events, or by
certain milestones. The specifications and contract arrangements are then written programmatically using programming logic and coding. The smart contract will then be deployed to the blockchain, where it can self-execute when the predefined conditions are met.

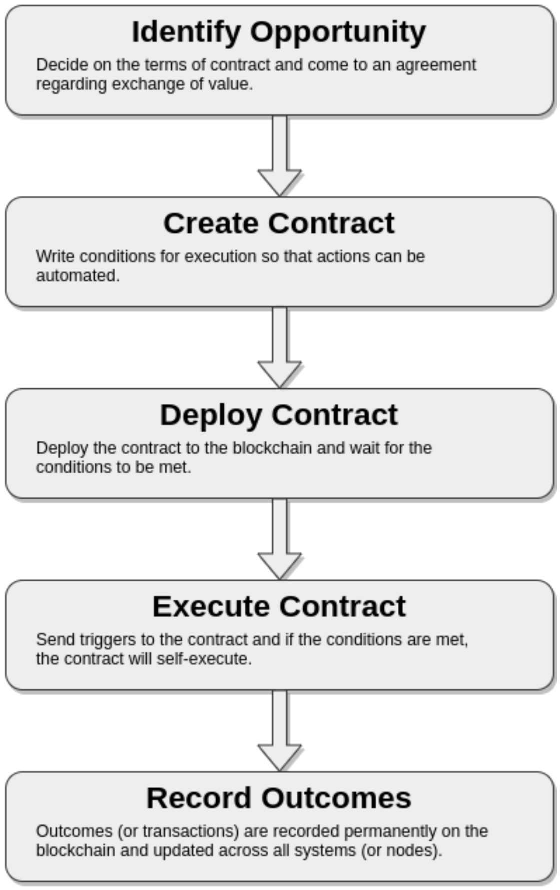

Figure 1: Working of a smart contract in a blockchain.

In order to initiate a smart contract, users must use an EOA to carry out a transaction with a Contract Account. This is encrypted with the initiator's private key and transmitted to other nodes in the blockchain. The other users can verify the authenticity of the transaction using the public key generated, to ensure that the initiator was indeed the one who triggered the transaction. Once consensus has been obtained from the majority, the transaction is added to the blockchain, the smart contract is successfully executed and its outcomes are recorded. As the state of the blockchain changes, it is updated across all nodes in the network and the outcomes cannot be altered.

1.5. WHAT IS A SUPPLY CHAIN?

A supply chain includes all of the processes involved in the distribution of goods or services, starting with production and ending with the consumer. With the rise of globalisation, resources are being identified around the world which is making the supply chain large and complex day by day.

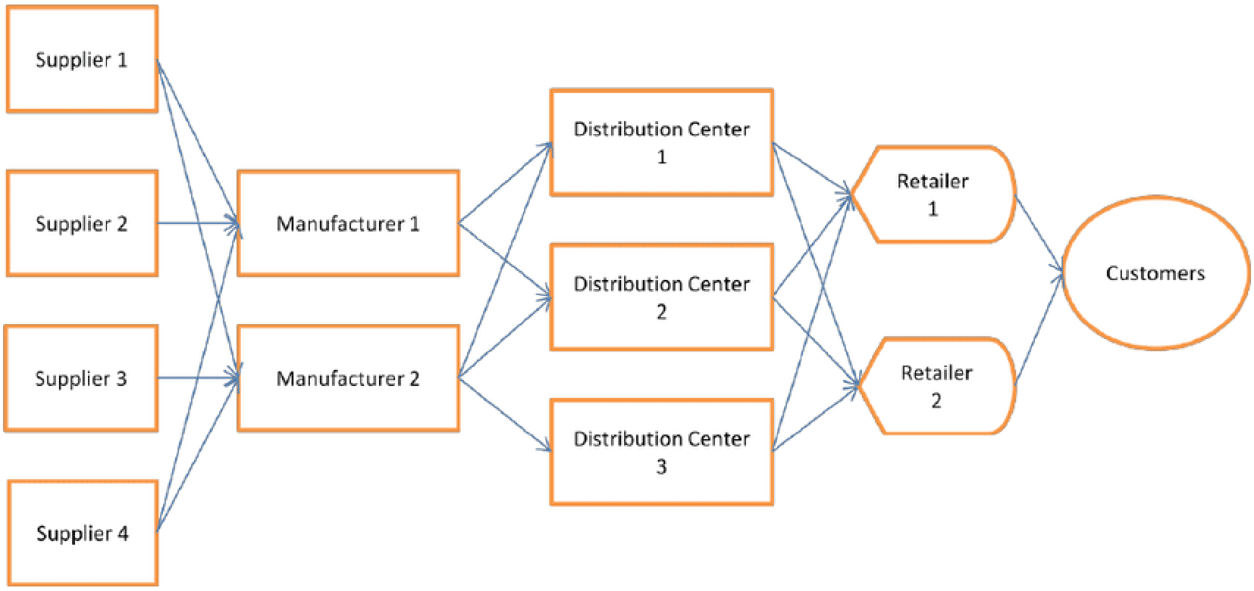

Figure 2: A generic supply chain network [13].

Given the complexity and diversity of supply chains, it is imperative that the multiple processes and relationships across the entire chain (inter-company, intra-company, and business-consumer) are adequately addressed to ensure the smooth operation of the supply chain.Therefore, the field of supply chain management (SCM) is crucial to the success of global businesses. The Global Supply Chain Forum (GSCF), a group of non-competing firms and a team of academic researchers, defines SCM as "the integration of key business processes from end user through original suppliers that provides products, services, and information that add value for customers and other stakeholders" [12].

1.6. CHALLENGES IN SUPPLY CHAIN

Given the complexity of supply chain networks and the business processes involved, there are many challenges associated with supply chain management. These challenges can be broadly categorized into two stages: the planning stage and the coordination stage.

The planning stage involves determining the level of supply and demand, whereas the coordination stage concerns the actual physical movement of goods.

<u>Planning Stage:</u>

- Demand Forecasting:

Forecasting market demand can be one of the most difficult problems in SCM, depending on the type of commodity. Demand for consumer staples or basic items (e.g., food) is usually non-cyclical and predictable. However, market volatility may be strong for consumer discretionary or leisure goods (e.g., apparel, technology) as there are a number of factors influencing a consumer's decision. Various models to forecast demand, using historical data, linear programming, and other analysis methods are being used to forecast demand. With the rise of big data, there is the potential to use more and better data analytics to help improve the accuracy of demand forecasting by tracking other observable characteristics.

- Inventory Management:

Inventory management involves the fine balancing act between ensuring sufficient supply to meet demand and preventing a supply glut, which cuts into profit margins. If supply is too low, profits are affected due to lost sales. There are several existing inventory management models, such as the Newsvendor model, economic order quantity model, periodic review, and continuous review models. These models work by determining the optimum quantity and timing to replenish inventory to maximize profits and reduce costs. The growth of data analytics can help to improve the accuracy of such models.

<u>Coordination Stage:</u>

- Information Sharing and Product Traceability:

Given the multiple stakeholders across a supply chain, each with their own goals, it is inevitable that information asymmetry exists. This poses a challenge in managing the supply chain without complete information. Without the availability of real-time information to track the progress through the production cycle (from raw material to component manufacturing, assembly, distribution, and all the transportation in between), it would be difficult to update and respond to unforeseen events.

- Managing Risks:

Risk assessment is a critical component of every enterprise. The ability to plan contingencies can help to reduce the effects of delays and ensure that activities will resume in the event of an emergency. Natural disasters or manufacturing delays will happen at any moment, but supply chain managers must have proper contingency measures in place to ensure that the supply chain is stable enough to accommodate unexpected changes without too much delay or effects on profits.

- Transparency:

As the regulatory environment and consumer behavior continue to evolve, there is a push for more accountability to ensure product safety and better handle recalls. This is particularly true in the food industry, where food safety and consistency are critical. Transparency and provenance are not limited to the food industry or safety issues. Consumers have become more discerning about the items they purchase, particularly given the abundance of options available today. They often choose products that are consistent with their principles and convictions. Greater transparency also helps keep parties in the supply chain accountable, as they are obliged to adhere to the standards set rather than cut corners for their gain.

- Trust and Reputations:

Sharing of information and increased transparency have been shown to improve confidence among supply chain stakeholders. As a result of the stakeholders becoming more associated with a shared interest and principles, trust fosters loyalty and reduces behavioral tension in the supply chain. Furthermore, confidence can provide a strategic advantage; as both sides are on the same page, the supply chain is more agile and can respond to circumstances and make decisions more quickly.

1.7. SMART CONTRACTS AND BLOCKCHAIN IN SUPPLY CHAIN

The introduction of blockchain technology ushers in the potential to solve some of the coordination challenges in supply chain management. Blockchain technology can reduce complexity and allow for greater clarity and trustless authentication across the supply chain by using smart contracts to manage the various transactions between parties. This would help accelerate the supply chain, make it more flexible, and strengthen relationships with partners.

Smart contracts can enhance supply chain management in three ways: transparency, traceability and efficiency.

coming from reliable sources, and consumers can have more confidence that they are purchasing a legitimate product. Another example of provenance is promoting transparency and socially acceptable practices by helping companies to disclose how they build their products and their environmental impact [14]. By allowing a digital form of identification to be created and stored on the blockchain, smart contracts can also help with transparent credentialing across supply chain partners [15].

Reputation and reliability can be recorded and managed on the blockchain as well. In a sense, the playing field becomes more level and meritocratic. Another benefit is that "blockchain ledgers establish a shared, secure record of supply chain information flows - a single version of the truth across networks for supply chain transactions, processes, and partners".

Figure 3: Summary of smart contract benefits in supply chain management.

<u>Transparency:</u>

Smart contracts can enhance transparency in the supply chain by recording the provenance of goods. This will assure manufacturers that their raw materials are

Information relating to the product (serial number, origin), transportation (date, location, number of containers), and accounting (purchase order, receipt, shipment notification) can be stored on the blockchain and accessible to relevant parties. This openness helps to ensure that all parties are on the same page and reduces the potential for conflict.

Traceability:

Smart contracts can enhance supply chain traceability by monitoring the product at any stage of the process, from raw material procurement to end-use delivery. This is possible through the use of smart sensors. Smart sensors are devices that take input from the real-world and use built-in embedded systems and other resources to perform predefined functions upon detection of specific input and then process data before passing it on to the internet. Smart sensors can potentially provide a wealth of data such as location, environmental conditions, and even product quality (especially for perishable goods). Supply chain managers will be able to make smarter and quicker choices with more detail and real-time feedback on inventory status.

In an environment where commodity rivalry is growing, being able to sustain supply reliability will go a long way toward increasing customer trust and their impressions of a brand. The ability to monitor inventory's chain of custody across the supply chain is particularly helpful in the case of a product recall or a safety incident.

Efficiency:

The use of smart contracts in the supply chain will improve productivity in two areas: process and cost. Smart contracts executed on a distributed ledger help to automate the dynamic multi-party processes found in traditional supply chains, increasing process performance. Smart contracts, due to their self-executing existence, can be used to immediately enforce "contractual rights and commitments, including provisions for payment and distribution of goods and services" [15]. This removes much of the time-consuming paperwork that was previously needed. By programming the contracts to execute only when certain milestones are met, parties can also be more trusting and not have to worry about unfulfilled obligations. For instance, by only executing the contract to pay a supplier once the product has successfully reached a predetermined port within a specified timeframe, the manufacturer is protected against excessive loss from rogue suppliers; the supplier is also incentivized to ensure that it meets the requirements set in the contract or risk not getting paid.

Another way to improve productivity is to reduce costs. Using reputable programming code that is readily flexible to enforce contractual agreements eliminates the need for multiple paper records that must be kept by - party's purchasing, accounting, or legal departments. This helps to lower costs and the amount of manual labour needed. Having a database where identity and reputation can be easily verified also saves on costs associated with conducting certification checks and building new trusted business relationships.

2. RELATED WORKS

The first point of reference for this research work was “Blockchain in Agriculture Traceability Systems: A Review” [16]. This paper is a comprehensive review of the introduction of blockchains into traceability schemes.

This paper highlights the real-world implementations, the challenges and also the future prospects of blockchain technology in the agro-food supply chain (or traceability systems).

“Agriculture Supply Chain Management: A Scenario in India” [17], this paper discusses the agricultural supply chain management in India. According to this paper, India's agricultural marketing sector is characterised by a fractured supply chain, massive post-harvest losses, multiple market intermediaries, higher transaction costs, lack of awareness, and several other socio-economic factors.

“Innovative Blockchain-Based Approach for Sustainable and Credible Environment in Food Trade: A Case Study in Shandong Province, China” [18], this paper discusses an innovative food trading system where an online double auction mechanism was used to eliminate competition. This paper proposes a new way of food trading system using consortium blockchain technology to meet the different challenges in a food trading system.

“Blockchain-based Soybean Traceability in Agricultural Supply Chain” [19], this paper proposes a purely blockchain based soybean traceability system which can be applied to any other crop or produce. The authors of the paper acknowledge that to date blockchain technology faces key challenges related to scalability, privacy, governance, identity regulation and others.

3. PROPOSED WORK

The proposed concept is to address three challenges faced in a manual supply chain:

- Identifying the origin (or provenance) of a product.
- Keeping track of the product in the supply chain.
- Creating a public database of supply chain partners (with reputation).

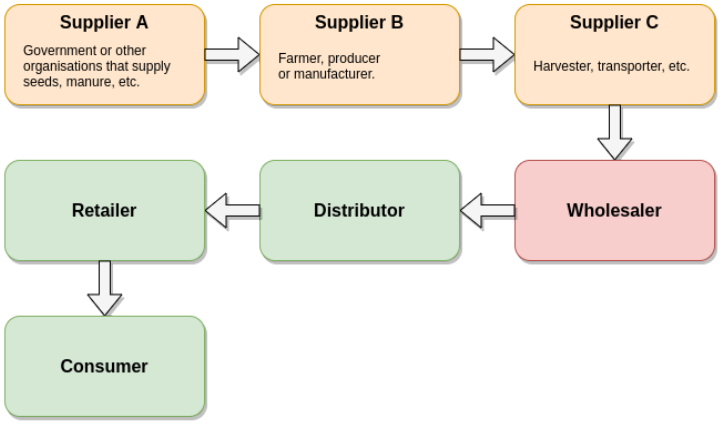

Figure 4: Flow of an agro-based supply chain.

The proposed concept would run on a blockchain that would be open to all supply chain members (consumers can access certain functions such as checking provenance). It can be deployed and administered by either the focal organization or a neutral third party.

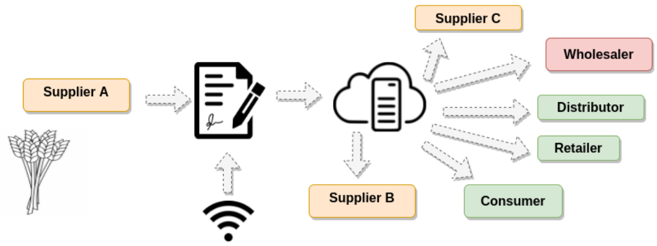

Figure 5: Using smart contracts to determine provenance.

To determine **provenance** (i.e., the origin of the supply chain), supplier A will be required to record its details and the details of its raw material to the blockchain. Through integration with a smart sensor, the location and time from which the raw material is shipped can be immutably stored. This will allow anyone, including the consumer, to access the information through the blockchain. (Figure 5).

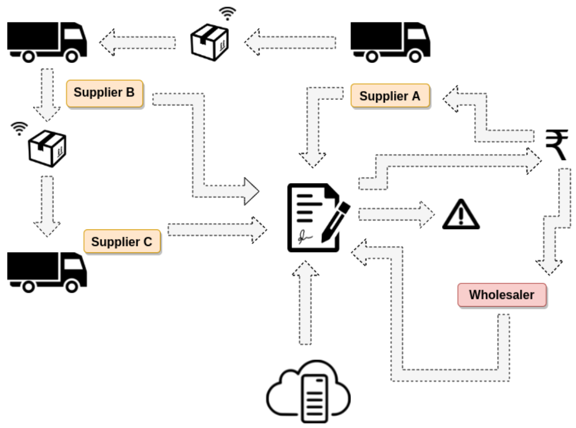

Figure 6: Using smart contracts to determine provenance.

For **tracking** of the product along the supply chain, each party will be required to record the details to the blockchain whenever they send out a shipment or receive a shipment. When a shipment is received, the receiving party will confirm that everything is in order. If the shipment arrives on time and at the correct location (verified by smart sensors), a payment in the form of cryptocurrency is triggered to the shipping party. (Figure 6).

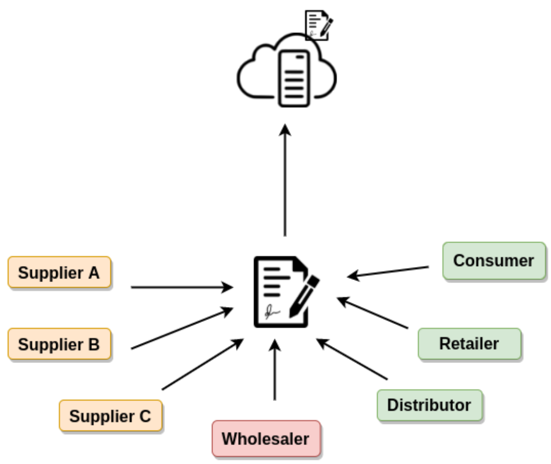

Figure 7: Using smart contracts for open database and reputation management.

4. PROCEDURE

- The **Provenance** smart contract allows supply chain parties and consumers to check the provenance of goods using their serial number or tag.
- The **Tracking** smart contract allows parties in a supply chain to track the shipment of goods and automatically execute payment in the form of tokens once every leg of shipment is completed, provided that certain predetermined criteria are met. There are two components to the contract - one for managing the tokens and the other for managing the shipments.
- The **Reputation** smart contract maintains an open database of suppliers/parties in a supply chain that can be accessed by all. In addition to supplier details, it also tracks the reputation of each party. This is done by calling the Tracking smart contract that has been deployed on the blockchain and accessing the reputation score calculated in there. To make it more convenient to browse the list of suppliers, functions to filter by type of goods and reputation have been created.

Functions of the smart contracts:

<u>Provenance.sol:</u>

- Records the details of the producer on to the blockchain.
- Certifies producers.
- Retrieves producer details.
- Records product provenance (origin) details on to the blockchain.
- Retrieves product provenance (origin) details.
- Accessible to everyone.

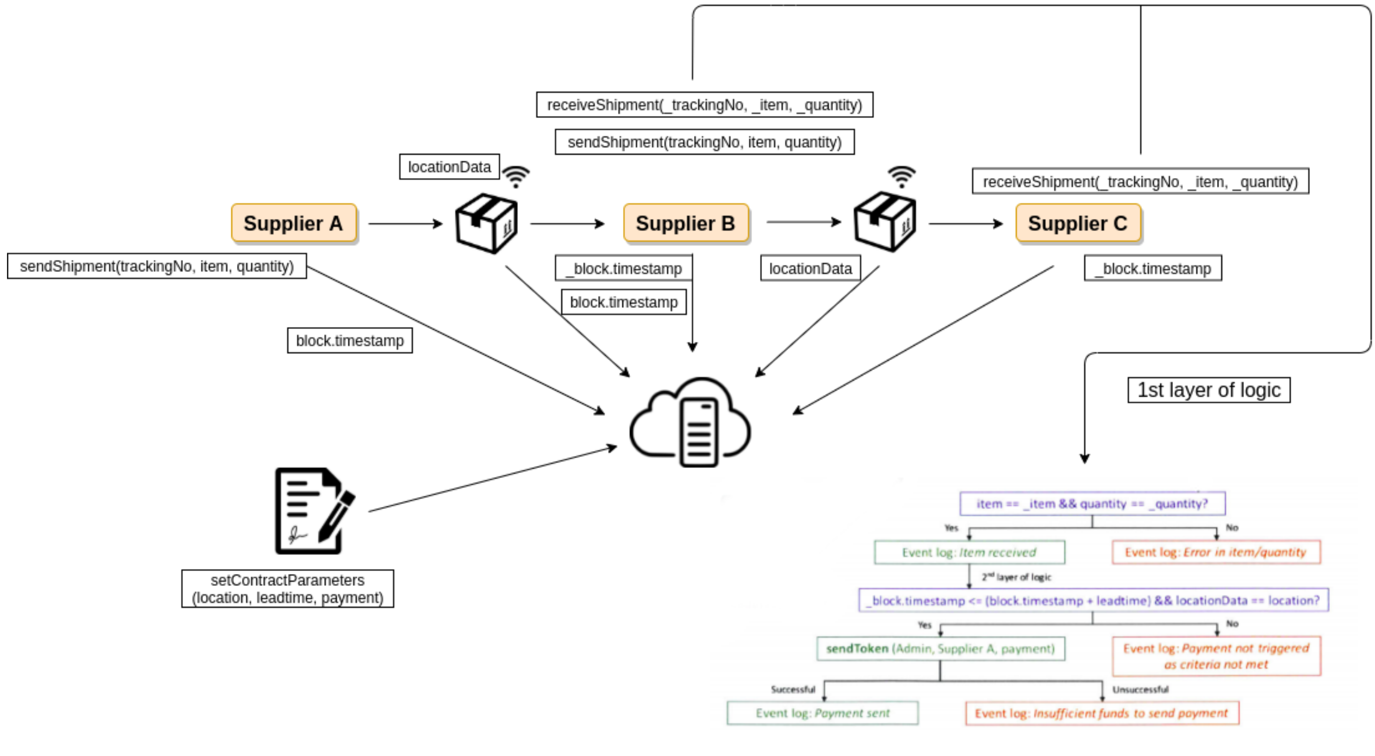

Figure 8: Logic flowchart for receiveShipment function in tracking smart contract.

Tracking.sol:

- Sets predetermined criteria for fulfillment of the contract.
- Records shipment dispatch details on to the blockchain.
- Records shipment arrival details on to the blockchain.
- Auto-executes payment in the form of token for fulfilled shipments.
- Retrieves shipment details.
- Calculates reputation score.
- Accessible to everyone.

Reputation.sol:

- Records supplier details on to the blockchain.
- Retrieves supplier details.
- Retrieves list of suppliers.
- Retrieves reputation score.
- Updates reputation score.
- Searches for suppliers by type of product.
- Searches for suppliers by reputation score.
- Accessible to everyone.

5. ALGORITHMS

Provenance.sol

Input: Details of producer like name, phone number, city, country and details of product like name, location (latitude and longitude) and timestamp of the block.
Output: Producer details, product details, certification of producer, and finding product

```
procedure ADMIN (producer, product)
    while (TRUE) do
        if (producer details are valid) then
            Add details to the blockchain
        else
            Exit
        end if
        if (product details are valid) then
            Add details to the blockchain
        else
            Exit
        end if
    end while
    for all(,,) do
        if (address is correct)
            return details of producer
            return  details of product
    end for
procedure ADMIN(address of product)
    while (TRUE) do
        if (address was found) then
            Delete details of producer
        else
            Exit
        end if
        if (product details are found) then
            Delete details  of product
        else
            Exit
        end if
    end while
end procedure
```

Tracking.sol

Input: Details of product shipment like item, quantity, location, receiverShipment status, and tokens for admin
Output: Success/failure of shipment, payment to sender for successful shipment

```
procedure ADMIN(details of shipment)
    set contract parameters for shipment
    while (TRUE) do
        if (sender product details are valid)
        then
            Add details to the blockchain
        else
            Exit
        end if
        if (receiver product details are
         valid) then
            Add details to the blockchain
        else
            Exit
        end if
        check contract parameters based on
        location, quantity, and timestamp
        if (receiver details are equal to
        contract parameters) then
            Transfer tokens to sender
        else
            Shipment failed
    end while
    if (address of product are valid) then
        return status of shipment
    else
        Error message
    end if
    if (to and from address are valid)
    then
        return transaction successful
    else
        return “Insufficient Balance”
    if (everything was successful) then
        return reputation score
end procedure
```

Reputation.sol

Input: Details of supplier like name, phone number, state and type of goods
Output: Details of supplier and reputation score based on status of shipment of goods

```
procedure ADMIN(details of supplier)
    while (TRUE) do
        if (supplier details are valid) then
            Add details to the blockchain
        else
            Exit
        end if
        if (supplier address is valid) then
            return  details of the supplier
        else
            Exit
        end if
    end while
    Input the details for tracking.sol
    Calculate the reputation score
    if (addresses are valid) then
        return details by reputation score
    if (addresses are valid) then
        return details by supplier
    end if
    if (transaction address is valid) then
        return balance of that account
    else
        Error message
    end if
    if(to and from address are valid) then
        return transaction successful
    else
        return "Insufficient Balance"
    end if
end procedure
```

6. RESULTS

Provenance.sol

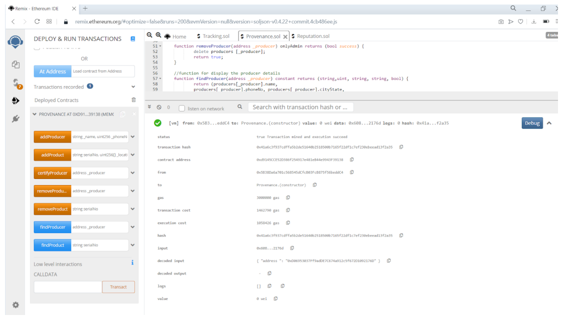

Figure 9: On executing Provenance.sol.

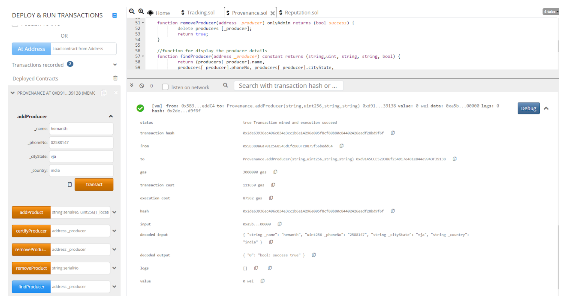

Figure 10: Output of Provenance.sol after adding a producer.

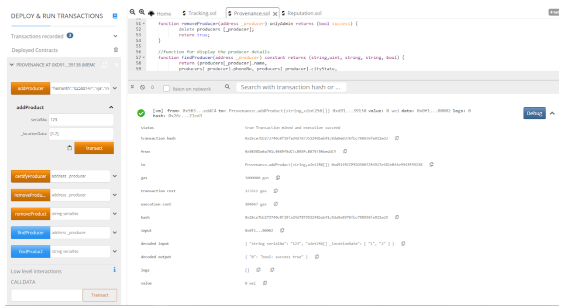

Figure 11: Output of Provenance.sol after adding a product.

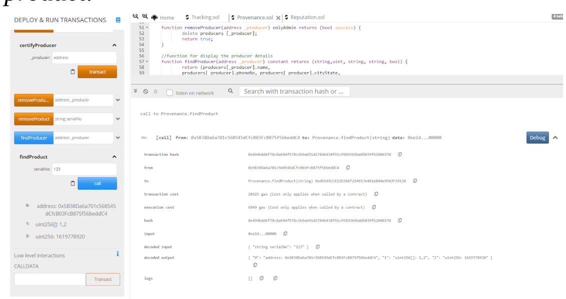

Figure 12: Output of Provenance.sol after searching a product.

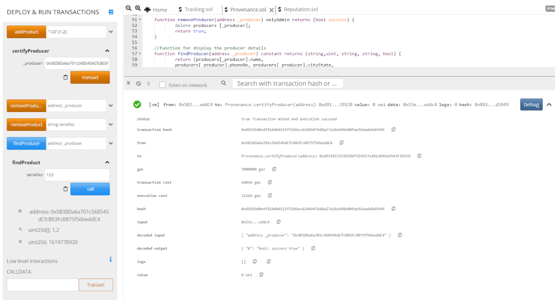

Figure 13: Output of Provenance.sol after certifying a producer based on their product address.

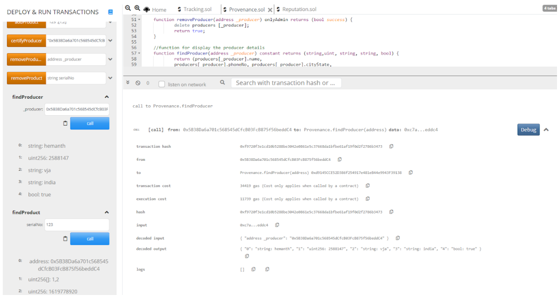

Figure 14: Output of Provenance.sol after searching for a producer.

Tracking.sol

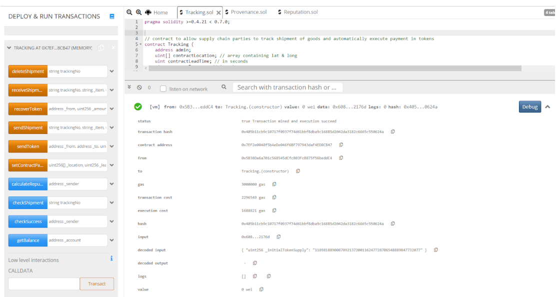

Figure 15: On executing Tracking.sol.

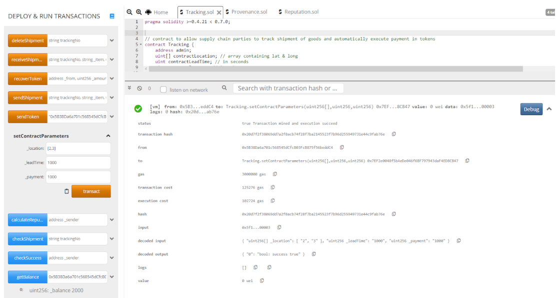

Figure 16: Output of Tracking.sol after setting Contract Parameter with initial balance of shipment sender as 2000.

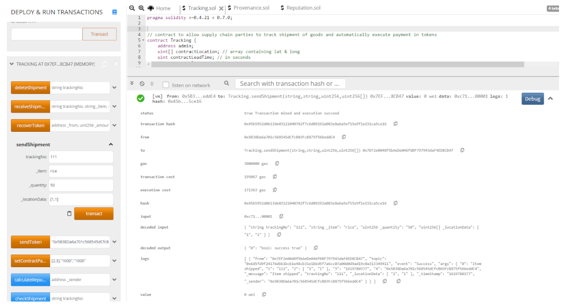

Figure 17: Output of Tracking.sol after sending a shipment.

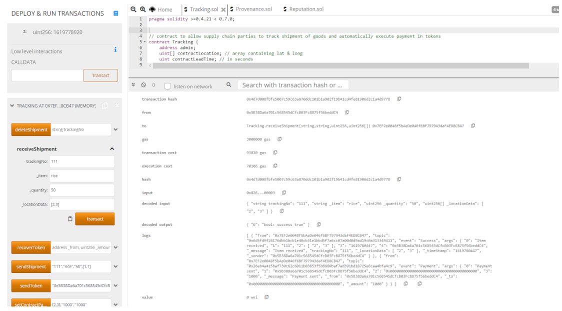

Figure 18: Output of Tracking.sol after receiving shipment successfully and payment is credited to the sender.

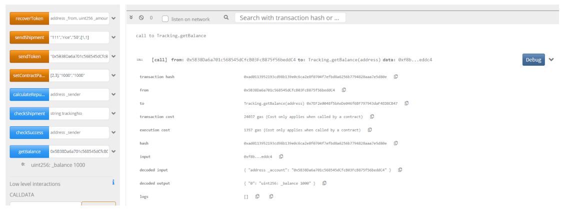

Figure 19: Output of Tracking.sol after receiving shipment successfully and payment is debited to the receiver.

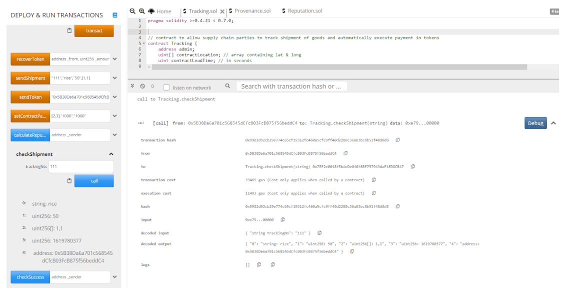

Figure 20: Output of Tracking.sol after checking if the shipment is successful.

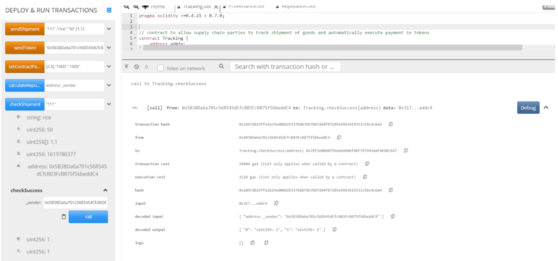

Figure 21: Output of Tracking.sol after checking if the payment is successful.

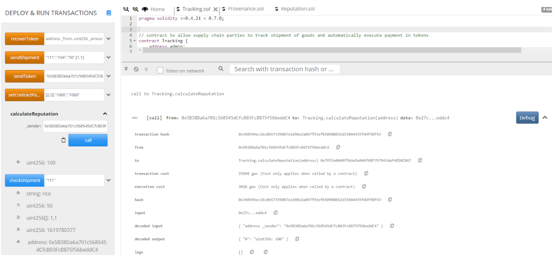

Figure 22: Output of Reputation.sol calculating reputation score after successful shipment and payment.

Reputation.sol

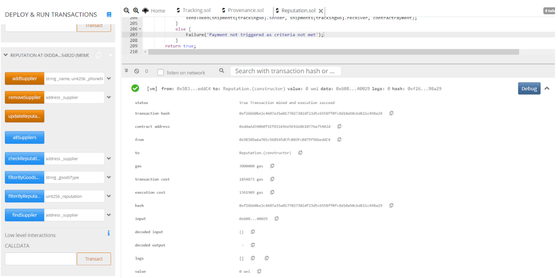

Figure 23: On executing Reputation.sol.

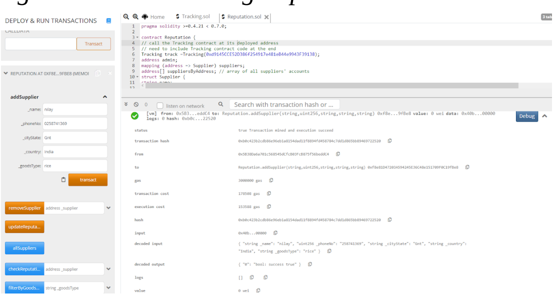

Figure 24: Output of Reputation.sol after adding a supplier.

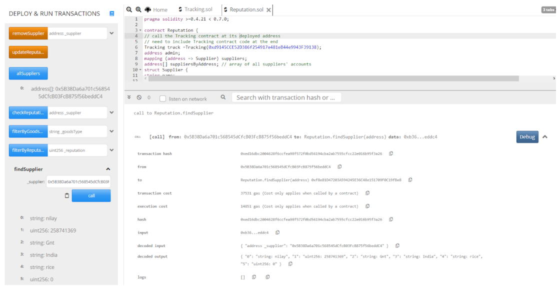

Figure 25: Output of Reputation.sol after searching for a supplier.

7. FUTURE WORK

In this paper, the authors propose an idea to implement an agro-based supply chain on a blockchain with smart contracts. In the future, the authors would like to test the smart contracts, implement them on a blockchain and run tests on them.

8. CONCLUSION

When Bitcoin was first introduced as a decentralised peer-to-peer network electronic payment method, nobody knew the potential of its underlying concept that came to be known as the blockchain. Blockchain was seen as a potential technology that can be used way beyond than a payment method. Researchers and students saw blockchain as a revolutionary technology that can be applied to various fields like the supply chain, for example.

This paper proposed a decentralised farmer centric agricultural supply chain that uses smart sensors, smart contracts, and blockchain wisely to efficiently manage a supply chain that ensures accountability and traceability to all involved parties. Smart sensors are used in this proposed model to update the time and place of the product to which it is connected, providing real-time information. With the aid of smart contracts, all of the data obtained at various levels of the supply chain is securely processed on the blockchain.

The ongoing research in blockchain technology and how to effectively use this technology to address real-world problems is still in its early stages. Well after a decade, blockchain technology continues to face problems in scalability, compliance, identity registration, privacy, standards, and regulations. Many research groups and start-ups are working to address this challenge and develop innovative approaches for dealing with real-world issues.

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