IE714: Quantitative models for supply chain management

Project report

on

A study on Integration of Blockchains to Meat & Poultry Supply Chain In India

By

Mayank Seth, 203190001

Chinmay Naik, 203190016

Abijith P Y, 203190024

Zubeen Kishore, 203190026

Under the guidance of Prof. Narayan Rangaraj

Interdisciplinary Programme in

Industrial Engineering and Operations Research Indian

Institute of Technology, Bombay Mumbai 400 076

ABSTRACT

Traceability and reliability are the most significant issues that some supply chains face in today's era. One of India's most important supply chains is the meat and poultry supply chain. There have been multiple occurrences of various incidents (e.g. bird-flu and food scandal) that have led to considerable losses in the meat and poultry industry. Most of the root causes of such issues trace back to a lack of transparency in the system. We propose a blockchain-based approach to solve these issues in this project to increase the traceability and reliability of the supply chain. We have tried to address this issue by collecting data about the product at each node of the supply chain, sharing the relevant data among each node of the supply chain using smart contracts, and using an application layer to access that data from anywhere. Smart contracts also prohibit data tampering, which makes transactions secured. We discussed the opportunities of this type of project in the Indian scenario and learned about the challenges in implementation from the management perspective of supply chains.

1. INTRODUCTION

Assume that we want to buy some meat, go to a store and the meat there looks fresh, so we buy them. However, how can we ensure that the meat we buy is safe for us to eat or not? Every one of us wants to ensure that the food is not adulterated, no matter what we buy or where we buy it from. Now imagine a situation where you would see where the foods are grown, inspected, refined and stored. The current scenario does not provide consumers or retailers access to such information. The current supply chain process is inefficient in terms of ensuring food safety at all stages. The food industry faces numerous challenges as a result of inefficiencies in the food supply chain.

However, by linking multiple stakeholders such as producers, processors, retailers, and consumers, blockchain, by the emerging distributed ledger technology, can enhance food safety. An immutable and transparent view of the transaction history will be available to everyone who is part of the network. Walmart, Golden State Foods, Dole, Nestle, McLane Company and Unilever are among the companies testing the potential of blockchain in the food supply chain.

1.1 Problems faced by the traditional supply chain:

1.1.1 Food Fraud

Tampering, improper representation, and deliberate substitution of food items have all shown an increment due to the complex global food supply chain system. According to reports, food fraud costs the global food industry 49 billion US Dollars each year. Milk and its products, tea and coffee, fruit juices, vegetable oil, various spices, seafood, and various other foods are among the most affected.

The meat scandal in Kolkata, which led to the seizure of 20,000 kg of rotten meat, is one of the significant issues that portrayed India’s flaws with food safety. Many similar cases of rotten meat or deliberate mixing of other meats have been reported throughout India. Such disruptions to a supply chain is not an issue specific to India alone. The 2008 Chinese Milk Scandal was another serious case globally, resulting in the deaths of six babies due to food contamination and the hospitalisation of approximately 54,000 babies in China.

Melamine, an organic compound, was found in infant formula, milk, and various other food components, which was the root cause of the scandal.

1.1.2 Foodborne Illness

One out of every ten people in the world gets sick after eating tainted or adulterated food. According to the WHO fact sheet, 420,000 deaths occur per year due to this alone. Foodborne diseases stymie socioeconomic development by putting a massive strain on the healthcare system, affecting trade and tourism, and wreaking havoc on national economies.

1.1.3 Illegal Production

Seafood is one of the most common categories with several reports of illegal production in the supply chain. The world's fisheries industry has to tackle the challenges of unreported, unregulated and illegal fisheries. According to reports, 24-36% of around 2.15 million tonnes of wild-seafood imported to Japan in 2015, valued between $1.6 to $2.4 billion, were of the unreported origin or illegal production[4]. Unlawful food production leads to both financial loss and infectious diseases.

1.1.4 Food recalls

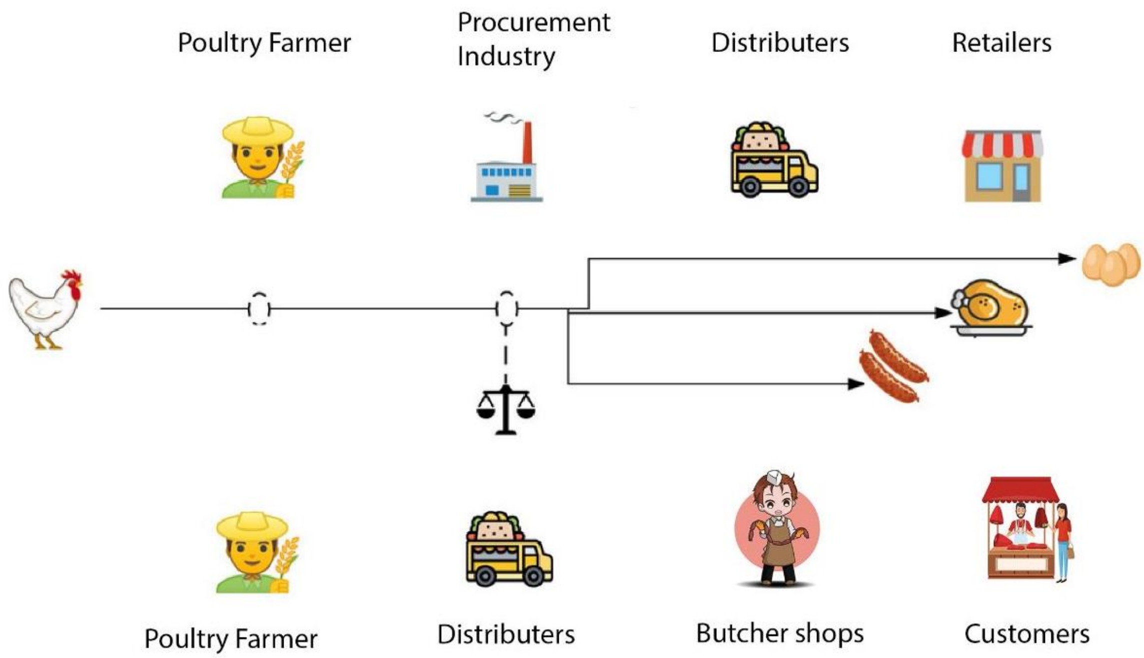
Government agencies sometimes ask for food recalls and do checking to find out that any possible allergens are present in the food products. Recalls of food often cost a lot to the stakeholders involved.

Average food recall cost, including loss of sales and branding damage, was reported at $10 million. In recent years reputable brands such as Pepsi, Kraft Foods, Coca-Cola, Cadbury, Nestle and Blue Bell Creameries have suffered losses from retirement and recall.

Apart from the above problems, because each partner in the food supply chain keeps their written records, it is currently impossible to identify the cause of a problem. Manual record-keeping is vulnerable to improper updates. In the event of a problem, tracking and tracing capabilities become problematic, resulting in delays in the investigation.

The blockchain could be one of the solutions that can keep immutable records traceable.

The current market consists of two major supply chains. The first one is a direct supply chain from farmer to the butcher shops and another one with the processing plants and then sold through specific outlets. They are represented below:



The ways to apply blockchain to these supply chains is discussed below in the article.

1. RELATED WORK

(Studying methods implemented by IBM Food Trust BLOCKCHAIN in the food supply chain: A research on Walmart)[2]

Walmart collaborated with IBM to develop and implement using blockchain technology in food products(2016). IBM's blockchain platform is based on Hyperledger Fabric that supports plug-and-play components such as modular architecture, consensus, and subscription services. It allows both efficient data capture and data control but most importantly, users own and control the information at any given time. The most critical aspect of trust is provided by Blockchain, which makes it more efficient and reliable in carrying out corporate transactions.

- **Walmart's Pilot Blockchain Application for Pigs Brought From China**

  This project was the first application (2016) on which Walmart tried to introduce the concept of Blockchain. Here the center examined the foodborne spoilage and developed risk assessment models which other organizations can use. Walmart's collaboration with government agencies was a crucial step for the success of its blockchain pilot.

> *Monitoring Phase from Farm to Slaughterhouse:-*

The first step in this process was to label each pig with smart tags (RFID) with barcodes to trace the product of packaged pork. The transportation trucks' global positioning, geographic information as well as conditions parameters such as temperature and humidity were monitored through sensors which ensured the product reached retailers in safe conditions.

> *Walmart Distribution Center and Tracking Products Up to the Store Phase:-*

Information about farm resources, batch numbers, processing data, soil quality, and fertilizers and storage temperatures, and shipment details were uploaded to an e-certificate and linked to the product package via a QR code. This ensured traceability for food safety purpose and consumer confidence. If spoiled food reaches the consumer, the system can better determine which products should be disposed of without endangering the entire product line.

- **Walmart Pilot Study 2: Traceability of Mangoes**

The second case study implemented by Walmart had a simultaneous pilot application using the IBM Hyperledger Based blockchain platform to track sliced mangoes from South and Central America to North America. Mangoes are shipped worldwide and are susceptible to Listeria and Salmonella spoilage.

> *Processing and Storage of Mangoes:-*

To determine the quality and marketability of mangoes at every stage, Walmart analyses fruit quality along the supply chain at the tree, harvest, packaging, wholesale markets, and retail outlets. This kind of analysis helped predict potential losses from stalk burning, bruising, physical damage, diseases, poor shipping from packaging to wholesale markets. At each stage, participants can collect and store data to compare industry performance beyond traditional practices.

>*Collection and Distribution of Mangoes:-*

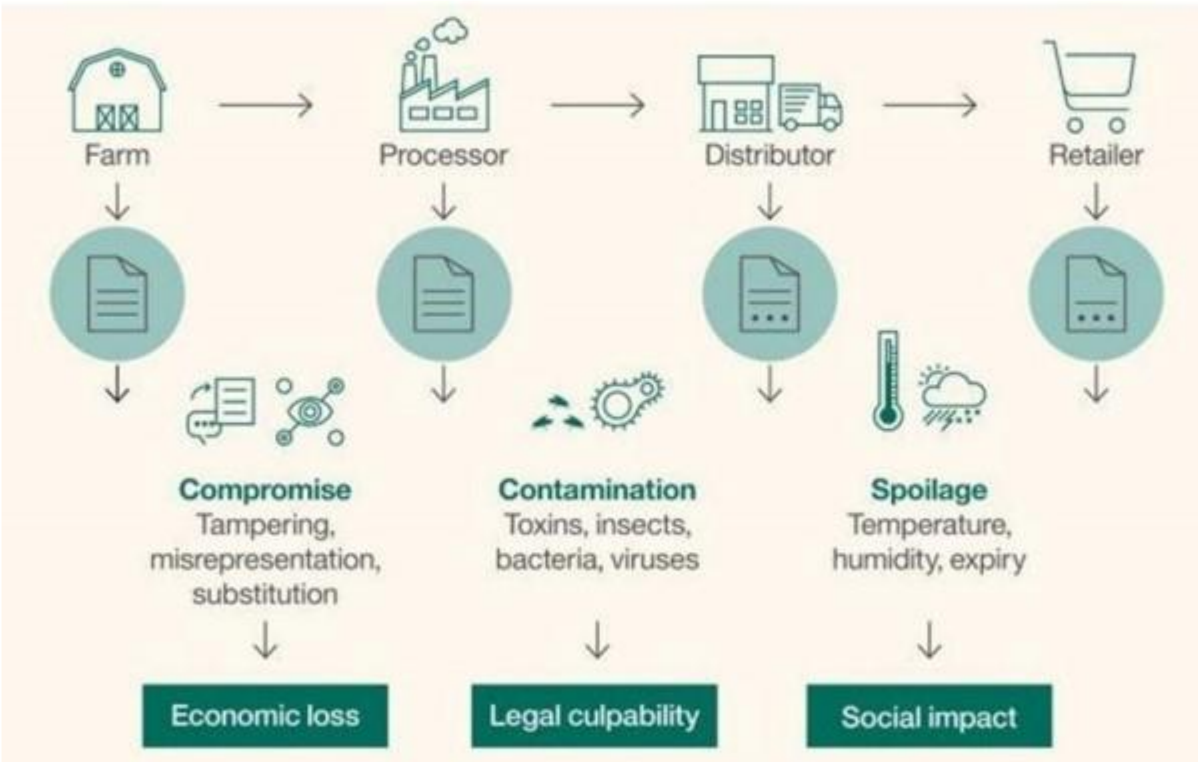
In distribution, blockchain-connected devices and smart sensors will record damage caused by excessive sunlight due to temperature and humidity.

>*Supermarket Phase:-*

Supermarkets will connect their enterprise resource planning and point of sale systems to the blockchain-powered platform and monitor every product sold. Retailers should be able to achieve customer satisfaction through transparency. While reducing risk, they can also reduce product recall costs and increase profits.

> *Consumer Phase:-*

When a consumer is harmed by food, Walmart will be able to obtain individual vital data, from a single receipt, the ingredients consumed, details of how and where the food is grown, and who is inspected, from pallet to package.



Walmart's blockchain pilot serves a larger purpose with the prevention, preparedness and proof, which has positively impacted Walmart. Walmart's blockchain needs to solve business problems such as time efficiency, cost reduction, long-term goodwill, and revenue generation. Using Walmart's existing devices and sensors, blockchain pilots identify systemic vulnerabilities in the food supply chain and go beyond technology and business to restore people's trust in food.[2]

2. BLOCKCHAIN

If you have heard about the term ‘blockchain’, you must have heard it in the context of another famous buzzword ‘bitcoin’. The concept of blockchain and bitcoin was first put forth by someone using the pseudonym ‘Satoshi Nakamoto’ in 2008. As a part of the implementation of the cryptocurrency, Nakamoto developed the first blockchain database. At the initial stage, the development of bitcoin was quite restricted because of its high fluctuation and complexity. However, soon it started to get more and more attractive because of the advantages of its base technology - blockchain. Some of the critical aspects of blockchain that caught attention were its distributed ledger, decentralised structure, transparency of information and openness.

Currently, we have three generations of the blockchain (Blockchain 1.0, 2.0 and 3.0). Blockchain 1.0 is only related to virtual currencies like bitcoin. Blockchain 2.0, along with bitcoin, involves many more new concepts like smart contracts, smart property, decentralised applications (Dapps), decentralised autonomous organisations (DAOs) and decentralised autonomous corporations (DACs). In more straightforward terms, we can say that blockchain 2.0 was evolved for applications in different areas of finance, in which one is supply chain finance. The most significant contribution of blockchain 2.0 was the introduction of smart contracts. Blockchain 3.0 does not restrict itself to currency and finance. It also covers areas like Government, health, science, culture and arts.

'Blockchain', as the name suggests, is a chain of records called 'blocks' which are linked to each other through cryptography. Each block contains a cryptographic hash of the previous block, a timestamp, and the transaction information. The timestamp stands as proof that the transaction data existed at the time when the block was published to get into its hash. These blocks in a blockchain contain the hash of the previous block and form the chain, with each of the additional blocks reinforcing the ones before it. Hence blockchains are usually resistant to any kind of data tampering or modification, as once recorded, the data in the past cannot be altered without altering all the subsequent blocks.

Blockchain can be beneficial to solve various problems if implemented in the supply chain problems. We have implemented this program on a local machine using google colab. In this implementation, we are trying to implement a simple version of blockchain for a short supply chain to issue to of the significant issues observed in the traditional supply chain structure:

1. Traceability: It should be easy and quick to detect the origin of the product.
2. Data tampering: If someone tries to tamper with the data, it should be possible to verify it at the given time.

Basics of Cryptography and Hashing:

Let us understand a few basic concepts in cryptography that stand as the base of blockchain technology.

<u>Encoding and decoding:</u>

Also known in cryptography as 'Encryption' and 'Decryption'. In encryption, we use a function to convert our message/data into some other data which cannot be directly understood. The encrypted data needs to be decoded or decrypted to get the original data back. A simple encryption algorithm is shown below:

Original message: 'supply chain'

Encrypted message: 361441256256144625000009064001081196

Encryption logic: Replace each letter with a three-digit square of its alphabetical order two-digit number (i.e. 001 for A, 004 for B,... 676 for z)

Now by reversing the logic of the encryption method, we get the decryption function. In the case defined above, the decryption function will work as follows:

Encrypted message: 004144225009121009064001081196

Decryption logic: Replace each group of 3 digit numbers by taking its square root and assigning the alphabet of that number (i.e. a for 001, b for 004, c for 009 and so on)

Decrypted message: ‘blockchain’

But, what if, after decrypting, we remove some data? That will make the current modified encryption impossible to be decrypted back to the original data. This concept of modified encryption is called ‘**Hashing**’. Hash is modified encryption where 2 data values can be encrypted and compared, but the encryption cannot be decrypted back to get the original data. A sample hash can be made as follows:

Original data: blockchain
Encryption: **0**04**1**4**4**2**25**0**0**9**1**2**1**0**0**9**0**6**4**0**0**1**0**8**1**1**9**6**
Hash: 01425092109640108116
Hashing logic: Remove all prime numbered digits from encryption (i.e. 2nd, 3rd, 5th… so on)

In the first block of our blockchain, we encrypt all the block data and store its hash. From the 2nd block onwards, we also use the hash of the previous block along with the data of the current block to get the hash of the current block. This, in a way, links all the blocks in a chain (hence the name blockchain), where each block’s hash in a way depends on all the previous blocks’ data. This makes it nearly impossible for someone to tamper with some data points and not get caught after checking as it disturbs the logic of the entire chain and gets detected.

3. REQUIREMENT ANALYSIS

The service objects of meat and poultry supply chain information management can be divided into three categories.

- **GOVERNMENT AND REGULATORY AGENCIES**

  The maintenance and guarantee of meat safety are some of the primary responsibilities of governments and regulatory agencies. Therefore, building a comprehensive information management system for the meat and poultry supply chain is conducive to improving governments’ management and processing efficiency. Thus, governments and regulatory agencies need to record all trading information in the meat supply chain through the information management system to facilitate the supervision of the entire meat supply chain and ensure meat safety.

- **ENTERPRISES IN THE SUPPLY CHAIN**

For the enterprises that occupy the main body of the meat supply chain, collecting and sorting data in the meat supply chain will help them master market dynamics, analyse changes in supply and demand, and improve operational efficiency and profits. The primary needs of meat supply chain enterprises are as follows: 1) data shared on the blockchain must have access rights to ensure that sensitive data are not leaked, and 2) the blockchain system should be easy to deploy and operate. Ensuring quality products are sold to consumers will create goodwill among consumers and help them attract a larger market.

- **CONSUMERS**

The supply chain information management system should provide consumers with supply chain information about the goods they buy to ensure the traceability of the information. According to consumer needs, the system should ensure that data cannot be tampered with to improve credibility. At the same time, consumers should control their data access rights to prevent the disclosure of sensitive information.[1]

4. PROPOSED STRUCTURE

We propose a four-layer structure for our information management system :

1. DATA ACQUISITION LAYER :

   In this layer, we will use EPS (Electronic Product Code) similar to a barcode that will be coded to construct a cattle breeding tracking system. This layer aims to improve the information traceability of the meat and poultry supply chain.

2. CLOUD SERVICE LAYER :

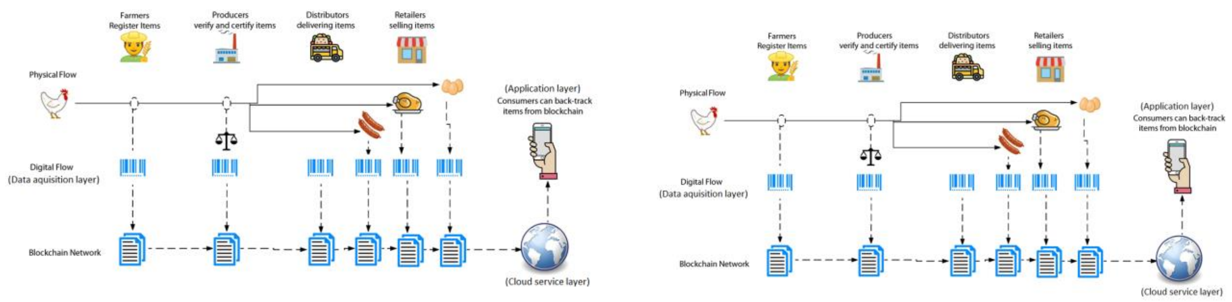
   To improve resource utilisation and reduce operational costs, we propose a cloud-based service layer. The main advantage of cloud databases is their convenient deployment and perfect security mechanism, which can realise rapid database deployment.

3. BLOCKCHAIN NETWORK LAYER :

   In this layer enterprises, regulatory departments will form nodes of the blockchain, building the blockchain network and deploying and implementing user-defined smart contracts.

4. APPLICATION LAYER :

This layer will be used to query and supervise the information of all roles in the supply chain. This layer will include the coding module, blockchain interaction module, data processing module and monitoring module.[1]



(Proposed blockchain system architectures)

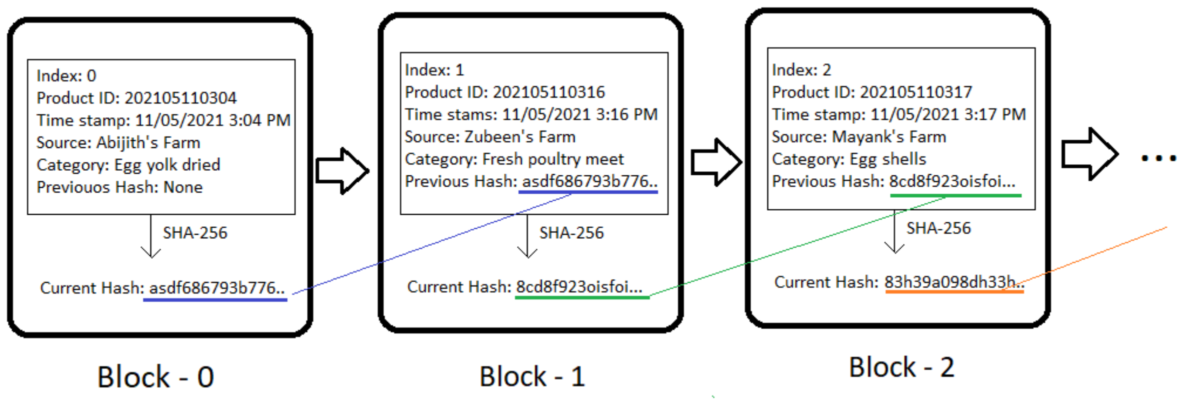
5. EXPERIMENTAL SETUP AND IMPLEMENTATION

We have tried to implement a short version of the blockchain to create a database for a handful of products in a poultry and meat supply chain (single-level) using a python code implemented on google colab.

Libraries used:
1. Hashlib : for creating hashes
2. Copy: for forking the current blockchain
3. Datetime: for generating timestamps
4. Random: for data generation
5. Timeit : for calculating time required for various processes
6. Pandas: for creating the Database
7. Pyplot: for creating graphs

Hashing Algorithm used: SHA-256.

Creating the Blocks:



(Representation of implemented Blockchain)

As shown here, we are also using the hash of the previous block in the encryption process of the current block, which makes the hash of each block dependent on the data of all the previous blocks. Hence this makes it near impossible to tamper with the data without disturbing the chain logic.[5]

Classes used:

1) **Class MinimalChain ( ):**
Creates a single level blockchain object for demonstration purpose
Attributes: self.blocks (Initializes the blocks and stores the relevant information)
Functions: def add_block : Adds a new block in the chain
def get_chain_size: Returns the length of the current blockchain
def verify: Checks the authenticity of current blockchain by verifying all hashes.
def fork: Creates a counter-chain by forking the current supply chain
def make_dataframe: Creates the database which can be visually represented

2) **Class MinimalBlock( ):**
Creates a new block object for the current blockchain.

Attributes: self.index = Index of the block
self.timestamp = Time-stamp at which the product was recorded
self.data = Description of product
self.previous_hash = Hash of the previous block
self.source = Source of the current product
self.category = Type/category of the product
self.product_id = Product ID.

self.hash = hash of the current product (Generated using all the above data)

Functions: def hashing = to generate a ‘SHA-256’ from given data
def generate_source = to generate and record the source of product
def generate_category = to generate and record the type of product
def generate_product_id = to assign an ID to the product
def verify = verifies the data of the given block (called in chain’s verify function)

Database representation: (In visual form):

	Product ID	Category of product	Source factory	Hash
0	20210511200728552617	Frozen edible poultry meat	Chinmay's farm	eb7eefea7929c6f7956cbde7a94c04da534499d0ef1b37...
1	20210511200728553874	Fresh edible poultry meat	Chinmay's farm	19e85702ed60c6998a0060778893d6c844db96c15351a6...
2	20210511200728553933	Frozen edible poultry meat	Abijith's farm	67e39dad5172fea972237acdf0f5a4f79013274ae2435b...
3	20210511200728553962	Eggs in shell	Mayank's farm	c3bb27f671283e020942b9a40a89e870a8298a7c11fcb6...
4	20210511200728553988	Fresh edible poultry meat	Zubeen's farm	e12e5ad732cf6565236cfee6a5e4bc35b89aea3525a1a4...
...	...	...	...	...

Handling the Data tampering issue: (Forking of the blockchain)

We use the verify function to detect any discrepancies found in the database. The output of the verification analysis looks as follows:

```
Verifying the blockchain...
Discrepancies found:

Wrong block index at block 6.
Wrong hash at block 6.
Wrong block index at block 119.
Wrong hash at block 119.
Wrong hash at block 146.
Backdating at block 146.
Wrong hash at block 713.
Backdating at block 713.
Wrong block index at block 1345.
Wrong hash at block 1345.
Wrong hash at block 1579.
Backdating at block 1579.

(Time taken for verification = 10.45 sec)
```

Handling the Traceability issue:

Here for the demonstration purpose we choose a few random products and trace their sources from our database. The output looks like this:

```
        Timestamp:              2021-05-11 20:07:28.573845
        Source of the item:     Chinmay's farm
        Type of the item:       Egg yolk dried
        Hash of block:          5201f93ff0eece869f093177d903569e61323cbbb237eda6ab2e9ebf9ec7191c


Your product 9 details are:

        Product ID:             20210511200728580872
        Index of block:         1723
        Timestamp:              2021-05-11 20:07:28.580872
        Source of the item:     Zubeen's farm
        Type of the item:       Frozen edible poultry meat
        Hash of block:          8992c0ade5f17dda231c41ad30cbc69ed323407f300bded78ff53fbdde062d6d


Your product 10 details are:

        Product ID:             20210511200728581718
        Index of block:         1773
        Timestamp:              2021-05-11 20:07:28.581718
        Source of the item:     Zubeen's farm
        Type of the item:       Eggs in shell
        Hash of block:          3cfab9e4e0c6e53ab6aeae96521d94da38e9c7569cacc8662b055eafb69eb501

IT TOOK 0.03 SEC TO DETECT ALL THE PRODUCTS' DETAILS!
```

```
The IDs of products I bought are:

20210511200728560162
20210511200728583757
20210511200728554826
20210511200728559909
20210511200728568082
20210511200728578735
20210511200728584692
20210511200728558697
20210511200728579842
20210511200728573406
```

(IDs of products to be traced)

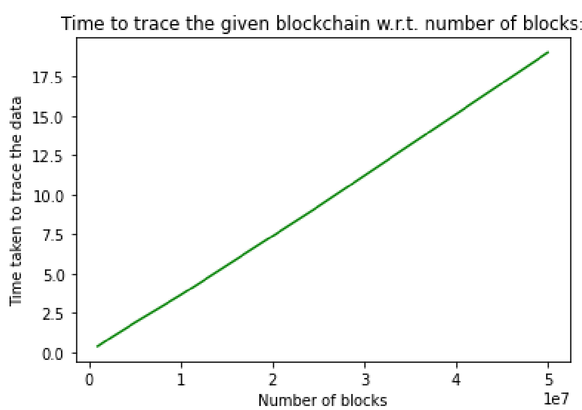
```
The details of the products you bought are traced as follows:
Found in 0.041 sec
```

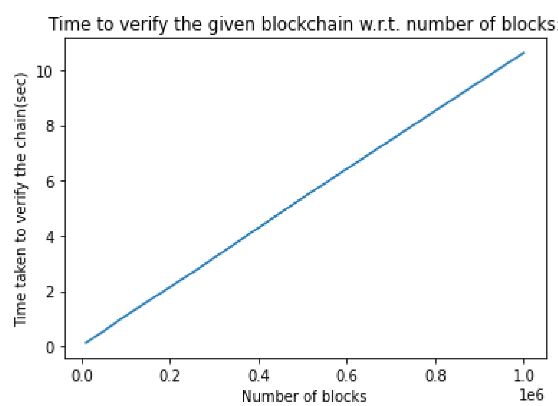
	Index	Product ID	Time-stamp	Source factory	Category of product
0	20	20210511200728554826	2021-05-11 20:07:28.554826	Zubeen's farm	Egg yolk dried
1	242	20210511200728558697	2021-05-11 20:07:28.558697	Chinmay's farm	Frozen edible poultry meat
2	325	20210511200728559909	2021-05-11 20:07:28.559909	Zubeen's farm	Fresh edible poultry meat
3	343	20210511200728560162	2021-05-11 20:07:28.560162	Zubeen's farm	Fresh edible poultry meat
4	872	20210511200728568082	2021-05-11 20:07:28.568082	Mayank's farm	Egg yolk dried
5	1239	20210511200728573406	2021-05-11 20:07:28.573406	Abijith's farm	Egg yolk dried
6	1586	20210511200728578735	2021-05-11 20:07:28.578735	Chinmay's farm	Fresh edible poultry meat
7	1658	20210511200728579842	2021-05-11 20:07:28.579842	Zubeen's farm	Frozen edible poultry meat
8	1891	20210511200728583757	2021-05-11 20:07:28.583757	Abijith's farm	Fresh edible poultry meat
9	1948	20210511200728584692	2021-05-11 20:07:28.584692	Mayank's farm	Egg yolk dried

(Data that was traced from the Blockchain Database)

Time taken for forking, verification and tracing the data w.r.t. the number of blocks:

All the functions/algorithms have linear time complexity, as shown in the graphs as follows.





Hence longer the blockchain more is the time needed to verify/trace, or more is the computational power needed to do it in desired time. So based on the computational strength of the system we are using, we can decide the size of the blockchain database to maintain.

6. RESULTS AND DISCUSSION

The proposed model will address some of the critical problems in supply chain networks but has some challenges. The main points are as follows:

- The regulatory department and the enterprises can quickly track problematic product's information through the blockchain network (within seconds), find the product's source, and judge whether the product is authentic and if it is being tampered with.
- Tracking down the source can immensely help the market health and make it more stable during any disturbance for all the vendors in the supply chain, increasing their income and bringing more players into the market for healthy competition.
- The 'trust problem' between different links in the traditional food supply chain can also be solved using a blockchain consensus mechanism. It will make the supply chains less susceptible to incidents such as food tampering and other scandals.
- The customer can easily trace the origin and other details of the product at any point in time to see if the product is as per the government norms.
- The main issue with implementing such a system is that there is no pre-established independent governing body to decide rules and regulations for such arrangements, which is also the problem with many cryptocurrencies based on blockchains.
- There is one more big issue related to the finance of implementing such technology in the supply chain. As this needs some capital investment which is problematic from the side of farmers, but we can have some possibilities as follow:
    - This can be implemented in our first supply chain structure, where big players like Big Bazar, Walmart, etc. These organisations can handle the cost of blockchain implementation in the supply chain and charge other vendors for it. However, in this type of structure, trust will not be built fully among different supply chain nodes as the blockchain is controlled by only one part, and they can be biased. Also, they may charge more to other vendors for their services which is not suitable for the overall health of the supply chain.
    - The second solution involves some other independent organisation (preferably govt. body) that can invest in the technology and provide the resources to all the supply chain vendors. They may charge for their service as well. They may also monitor the supply chain if it follows all the rules and regulations.
- The farmers and small vendors may not be well versed with the technology; training them will also be difficult in this structure.

7. CONCLUSION

The proposed system makes it easier to track the product's origin at each node of supply chains and make customers more confident buying meat and poultry even if one part of the supply chain is affected by problems like bird-flu or some other contamination issues. That will lead the business to be more stable and grow faster and give farmers a more reliable source of income that previously used to disrupt in such cases and affect farmers adversely. However, the implementation of blockchain has some constraints due to capital investments, and the absence of regulatory authorities and required infrastructure leaves this with some improvements to follow.

8. FUTURE WORK

We have talked about disruptions in our project but did not deal with them in this case study. Suppose several producers are supplying meat and poultry to a market from different parts of India. Suddenly, some of them stopped supplying products because of some disruptions. We need to reorganise our supply chain structure. This will give rise to a **capacitated facility planning** problem in which we have different levels of operation in the supply chain according to the availability and capacity of various vendors in the supply chain.
One can model the problem based on research work "Planning for Disruptions in Supply Chain Networks" (Synder et al.)

Smart Contract will play an essential role in information management in blockchain-driven supply chains. So to customise the smart contract to meet different requirements of different organisations is going to be a crucial step that will help organisations conceal their private information. These contracts will help government bodies keep a record of trading activities and help them stop malpractices. Apart from this, these contracts can also be used to monitor current demands and manage inventory accordingly.

9. ACKNOWLEDGEMENTS

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