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Reduce food crop wastage with hyperledger fabric-based food supply chain

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Abstract - **Food is the utmost important thing for every living being. The quality and safety of food has become a crucial factor in the food industry. Most of the customers tend to pay more attention to food safety and seek to get food from verifiable resources. To improve this trustworthiness Distributed Ledger Technology (DLT) - based Food Supply Chain (FSC) plays a vital role because of its traceability. There are multiple actors involved throughout the journey of FSC and with the high visibility of data in DLT, everyone can ensure trust. The transparency of data itself is a reason for some to opt-out because some of their private data can be exposed to others. Hyperledger Fabric (HF) based FSC can address that matter as it supports permissioned network solutions. Though there are a lot of solutions available in a similar kind of approach, whether the crops take their journey throughout the FSC without any wastage, is still questionable. This study focuses on reducing wastage of food crops as they take a long journey in their raw state and possible hazards are high. It discusses farmers' behavior based on the Sri Lankan context and how it accompanies food crop wastage. Further, this paper ruminates the other possible crop wastage that can take place in FSC and how to eliminate it with the proper involvement of knowledgeable and authorized parties. Then, the study explores how all the parties can collaboratively join the FSC based on HF so that everyone can benefit. Finally, it concludes on how such design is effectively contributing to reducing food crop wastage in Sri Lanka (SL).**

Keywords - crop, farmer, food, hyperledger fabric, lock chain

I. INTRODUCTION

The food industry is a globally widespread industry where agriculture plays a main role. Most of the humans' food needs are met by crops like vegetables, fruits, potatoes, and grains [1]. From production to consumption, crops go through many different stages in the FSC. FSC has become an extremely complex and long process as it involves many actors like farmers, transporters, wholesalers, retailers, end consumers, and many more on different scales [2]. As the participation of different parties increases, many issues such as lack of communication, transparency, accuracy, mutual trust, and traceability arise. There is a growing interest in the technology world to design systems based on DLT for FSC to address such issues [3] – [7].

DLT is involved in a distributed style with no central governance for the data [8]. All the technologies engaged with DLT work in a similar manner which ensures tamper-proof data. Blockchain is one of the DLT types and has great potential in various industries with the availability of vast technology platforms. As it supports immutability and traceability, those who join the blockchain network can expect high trust. It is an ideal solution for any e case where trust is required as a key feature [8]. So, it plays a vital role in FSC in which contributors can have mutual trust. Food consumers can ensure their food safety and nutritional value, and anyone can know the path food has taken from its origin to destination.

Blockchain's high data transparency has benefited some industries, but some are reluctant to get involved. Because some people are afraid that their information will be passed on to the competitors [5]. In that case, it would be better if they could interact with the FSC while keeping their data confidential and HF could do the same. HF provides an authorized way for each actor to join the network, and the literature explores it the most.

Although we can improve the privacy and trustworthiness of FSC with HF-based supply chains, there are many stages throughout the chain where food wastage can take place. Due to the high complexity associated with FSC, measuring food loss through the chain is a difficult process. Farmers can be known as the heart of the FSC, and the initial point of food wastage starts there. The issues faced by farmers and their behaviors have a great impact on their harvest which may indirectly cause food loss. The post-harvest period is another main stage where food wastage happens. With the proper involvement of actors in the DLT based FSC, food wastage and loss can be minimized. Further, this study is based on the SL context in discussing the problems associated with food cultivation, transportation, and marketing. There can be information that can suit the global context. But, in developing countries, most of the issues are very different due to factors like poverty, improper education, and cultural challenges [9] [10].

The SL government has taken various measures and legislation to prevent food loss and wastage [9]. But, the problem lies in the challenges they face in implementing them. If everyone meets at FSC, to get together and go on this journey, they can solve a lot of problems in a way that is profitable for everyone involved. To facilitate that, HF-based FSC is a great solution because there we can make the participants work more credibly in a way that is transparent.

Therefore, this paper provides a solution on how to use the HF-based FSC to minimize food crops wastage in the process of supplying food in Sri Lanka from the beginning of growing crops to the consumer's home. To incorporate that, the rest of the paper is arranged as follows in a sectioned order; literature review, solution overview based on the literature, results and discussion, and conclusion.

II. LITERATURE REVIEW

DLT systems have a distributed database shared among each node in the network with no central authority

[8]. Among the notable popular DLT platforms, blockchain is the frequently associated one, having gained its popularity with the cryptocurrency bitcoin introduced by Satoshi Nakamoto [11]. Because bitcoin works so reliably in transactions where fraud is almost impossible, many people are curious about how to use the underlying technology when developing applications where trust plays a crucial role [12].

A. *Blockchain*

Blockchain is a decentralized, distributed ledger that facilitates recording and tracking of transactions. Like any other database, blockchain also stores data. The key difference of blockchain with a typical database is that it stores transactions in a data structure called blocks instead of a predefined table structure or file format. If it is described from its simplest form, the block consists of transactions data, nonce, the hash of the previous block as well as the hash of itself [6] [8] [11] [13]. So, each block in the chain is cryptographically linked together. This type of chain is called a ledger and there are multiple copies of the same ledger stored in a distributed peer-to-peer network. When a new transaction occurs all the peers work upon an inbuilt consensus protocol, and it is approved upon 51% agreement of the peers. When the network grows, it becomes more robust and it is almost impossible to tamper with other data although someone spends more time and applies computational power more than 51% [8] [14]. So, the data immutability offers a high tamperproof nature and can rely more trust on the data.

Although blockchain is often identified to have two or three main types, it could use the four types below: public, private, consortium, and hybrid [13] [15] [16]. In a public blockchain, no restrictions are applied, anyone can engage with transactions, running nodes, and mining. A private blockchain is a closed network and is operated by certain members only, but everyone has visibility over the data within the network. Consortium blockchain differs from other blockchain types. It is not only a closed network but also members have accessibility over a permission manner. Hybrid blockchain is a combination of both public and private blockchains. With the evolution of blockchain, many platforms have emerged. Among them, Ethereum and Hyperledger frameworks are popular at enterprise level [16].

Ethereum's main network is a public blockchain and it can be deployed as a private network also [17]. But it cannot control its data visibility in a permissioned way across the participants i.e. someone to be visible and someone to not. In such cases, HF is the ideal solution provided by the Hyperledger platform which is an open source community that provides frameworks, libraries, and tools for enterprise blockchain solutions [18]. HF is the most active and mature project in Hyperledger projects backed by Linux Foundation with a strong development community. HF is more suitable for multi-stakeholder businesses due to its unique features associated with the identity of the participants, data privacy, confidentiality, and performance than other platforms [19].

B. *Hyperledger Fabric(HF)*

HF is a DLT platform that has a pluggable modular architecture [20]. Therefore, it can be easily adapted to satisfy most of the business's needs. Also, its permissioned nature allows businesses to operate in a more confidential manner which is a major concern enterprises pay attention to, related to their data privacy [21]. With its latest version 2.x, HF provides a new architecture for the transactions, called execute-order-validate. Over theearlier approach, the order-execute new approach has a huge impact on the performance [20] [22]. It first executes the transaction using chaincode. According to the endorsement policy when enough peers agree upon the correctness of the transaction, transactions are ordered with consensus protocol which is also pluggable. Ordered transactions are validated by peers against the specified endorsement policy. So, it eliminates non-determinism rather than being limited to domain-specific languages, it allows writing smart contracts in standard programming languages such as Java, Go, and Node.js [20].

When creating a HF network understanding the functions of its components and how they work collaboratively to form a secure network is very important. Although there are many components involved with HF, ten identified key points are discussed here which describe HF architecture in detail.

1) *Ordering Service:* Every HF network consists of at least one ordering service. When clients send endorsed transactions to the ordering nodes, they come to a consensus on the order of the transaction by executing a consensus algorithm. The consensus algorithm is pluggable and Raft is the recommended one. After the transaction order is confirmed, they form them into blocks and send those to the endorsing peers which are pre-defined in the endorsement policy. The earlier versions of HF used the Kafka and Solo consensus algorithm to order the transaction, and it is deprecated with the HF version 2.x whereas Kafka makes additional overhead to the system administration and Solo is for test only and consists only of a single ordering node [23].

2) *Peers:* Peers are the fundamental element in the HF network. They are owned and maintained by a relevant organization. They host the ledger and smart contracts specific to them. Peers can hold multiple smart contracts (when packaged it is called chaincode) and multiple ledgers. Peers validate and commit the transaction blocks into the ledger [24]. So peers basically read, write operations to the ledger by running chaincode[25].

3) *Applications:* Applications can execute chaincode hosted in peers by connecting them. When they send the proposal to the peers to read or write data, peers check its correctness by endorsing it, and a response is sent to the application. Then the application sends a request to ordering nodes to order the transaction. Ordered transactions blocks are sent to the peers and peers update their ledger and the application receives the ledger update event [24].

4) *Organization:* An organization is a logical entity in a HF network and is also known as a member. The organization is defined by the root certificate specific for the organization and is stored in Certificate Authority (CA). The organization represents a physical separation of their Certificate Authority (CA), Membership Service Provider (MSP), and peers. Each

organization added to the channel at the channel creation time is a part of a consortium which is again a collection of organizations. The HF network can consist of one or many organizations[25] [26].

5) *Certificate authority (CA):* CA is responsible for giving certificates to components of its organization. CA issues key-value pairs (public and private key) and can be used to prove the identity components like peers [25], [27].

6) *Membership Service Provider (MSP):* MSP is a directory that includes certificates and private keys for each identity that is generated by the CA. So MSP contains a list of files and directories representing those permissioned identities to the fabric network. It allows organizations to manage their members under MSP. When organizations perform different business modules in multiple channels they can have multiple MSPs by properly naming them [27].

7) *Channel:* Channel is like a sub-network within the HF network that allows organizations to communicate privately[25]. The organizations are invited to join their peers to the channel for validating the transaction on the channel. Organizations can only access the data of the channels they have joined, the channels they have not joined arerestricted [28]. Within a channel also there can be one or more private data collection (PDC). This allows the organization to expose certain data to all channel members while keeping some part confidential within another subset of members in the channel [29]. It minimizes the number of channel creations with extended privacy.

8) *Smart contracts and chaincode:* Smart contract contains the business logic and executes upon ledger to read and write data[30]. The related smart contracts are packaged before they are deployed to the blockchain network. Packaged smart contracts are known as chaincode. Chaincode is installed on peers and invoked by the client application through HF Software Development Kit (SDK). When a smart contract generates a transaction, the endorsement policy associated with the chaincode defines which members should approve the transaction against its validity. When the transaction is signed by a required number of members, the transaction is indicated as valid or invalid. Then that information is added to the distributed ledger. But only valid transactions are updated to the world state which represents the current state of the latest transactions. To be able to execute efficient queries word state supports state databases, level DB, and CouchDB [31].

9) *Ledger:* In HF network ledger can be identified intwo pieces i.e. the blockchain immutable ledger with all history of transactions distributed in the peers and world state with the current value [31].

10) *Policies:* Policies make HF distinguished from other networks. Unlike the other blockchain platforms, HF cannot use any node to validate the transaction. “Who is going to do what” can be clearly defined as a set of rules [32]. Policies containing those rules are stored in a configuration file. So access to the resources within the network is restricted and only permissioned ones can access them. Policies can be defined before the network is launched or at the time the network is functioning. So those are implemented in different levels of the HF network. Policies in the system channel configuration govern the consensus used by the ordering service and which members are allowed to create new channels. Policies in the application channel configuration govern which members are allowed to join the channel and which members can approve the chaincode to be committed to the channel. Policies defined in Access Control Lists (ACLs) refer to policies defined in an application channel configuration and extended to control additional resources. Smart contract endorsement policies define how many peers need to execute and validate a transaction against a given smart contract [33]. So the default policies in the HF at its network first stage can be overridden at any time according to the business requirement and provide governance over the privacy.

As a summation to all these, since the HF network is highly configurable it allows any component to act in a pluggable manner. Also, with proper endorsement policies, data can be shared within the network on a need-to-know basis [19]. As of this modular architecture, anyone can design their network in high-performance, scalable, and confidential ways [34]. More importantly, in the HF network trust is not dependent only on its immutable ledger., Since the well-identified participants are engaging all the time, more trust can be ensured and any fraud can be easily identified which prevents them from tampering the data.

III. Issues in Sri Lankan Food Supply Chains

FSC in SL is mainly built on farmers, wholesalers, transporters, retailers, and end consumers. Normally wholesalers buy crops from the farmers. Then wholesalers use transporters or their own transportation to receive goods. Retailers buy crops from wholesalers or directly from farmers and then go to the end consumer. Most of the time this supply chain takes place based on everyone’s knowledge and experience. The educated people are not involved in this supply chain process and hence a lot of misbehavior can occur in various stages of FSC [35].

Fig.1 displays the exact problem of the current supply chain. Red lines indicate how intermediate parties directly involve farmers and it will indirectly affect the synchronized supply chain process. Green lines display the ideal flow and still isolated educated resources, and regulatory bodies are not involved.

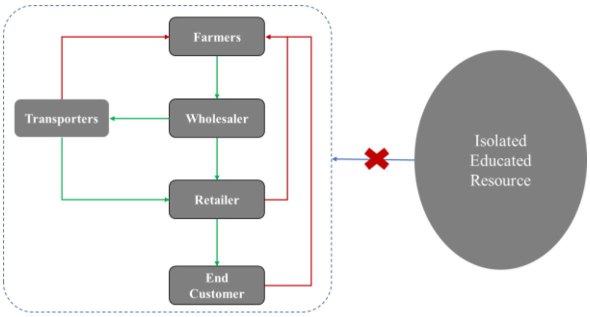

Fig. 1. Sri Lanka supply chain in high-level

In SL most of the farmers cultivate any crop according to the current trend and they do not foresee the future demand. Many of them count on facts like how the fellow farmers made profit during the past and tend to cultivate the same crop. During the harvest season, it will result in the same product being so abundant in the market and demand gets lower. According to the equilibrium theory in economics, when the price is high, the supply increases and it lowers the demand and ends up with a low price. The same theory is applicable here and farmers get low profit and their motivation to sell their harvest is also lowered [36]. With this disappointment, they sometimes destroy their harvest. Sometimes farmers tend to commit suicide due to debt [37]. Not only does it cause huge food wastage in the country, but that causes economic loss too. Further in parallel to growing crops, supplying fertilizers, insecticides, pesticides and herbicides are also important. If it is not received on time farmers suffer low harvest. Although they receive those, there can be a lack of knowledge on how to use them properly. Such activities often engage with the help of oral knowledge. Although there are many regulatory bodies established in SL to help farmers, because of the lack of communication, this knowledge transfer does not properly happen. All of these factors contribute to a lower yield than what they are able to obtain. So, the wholesalers will not be able to fulfill the required demand. In this situation, wholesalers will search for alternative solutions and will end up finding low-quality crops. Farmers also suffer from less ROI (Return on Investment).

As per the study, most of the food supply chains in SL have no proper methodology, and instead, it is a kind of ad-hoc process [35]. Many problems in the process take place post-harvest [36] [38]–[43]. Especially when loading and unloading harvest there is no defined process to check how the quality of such work is carried out. Overloading the sacks of crops and sometimes throwing the sacks into the vehicle without properly stocking, usually occur. This entire food transportation is not properly monitored and regulated. So much food loss and wastage happens during transportation [36] [38] [40] [43]. This causes not only food wastage but also food safety is at risk. Raw food such as vegetables and fruits are perishable, and the shelf life is severely reduced. Customers have to buy poor-quality food with lower nutritional value. Sometimes customers are even tempted to throw them away once they bring them home. When this happens in many homes, there is a huge food wastage in the country. It is a pity that when a significant number of people in the country are starving, they are not able to utilize the product for other reasons.

So, there is a need for a supply chain eco system to minimize the food (mainly crops) wastage by improving the quality of it. The solution for this issue should come as a global solution and should involve each minor party who is directly or indirectly involved with the FSC. Also, there should be strong technological solutions where transparency, trustworthiness, immutability, and privacy are major concerns [3] [5].

IV. Solution Overview

This solution is guided by the Design Science Research (DSR) methodology to take the various decisions over the designed artifact, HF based FSC which is used by the context of farmers, wholesalers, transporters, retailers, and regulators. When considering the relevance of the solution some of the technical barriers were identified in between context and the design and those were overcome based on the output obtained from the literature review. So the following solution demonstrates in detail how farmers, wholesalers, transporters, retailers, and regulators are successfully joined to the HF upon an invitation from the network initiator. Later it presents how more parties like knowledgeable persons, fertilizer, or chemical suppliers are also included in this FSC.

The diagram in Fig.2 explains the basic structure of the HF-based blockchain network for the food crops supply chain. Six organizations are identified as main contributors, and channels are identified based on the data privacy requirement on the organizations. Five main applications are identified to support end-users to interact with the network. Four smart contracts are deployed to support storing private data separately and one contract is used to handle common queries required for all the nodes. Seven separate ledgers are used to maintain private data and it is bound with peers connected with the channels. When the number of components increases, complexity will be added to the design. But once the network is consistent there is no development complexity as HF provides pluggable modules in a configurable manner.

A. Organizations

Followings are the main organizations in this design.

- Farmer – Grows the crops.
- Wholesaler 1 – Buys crops from the farmer.
- Wholesaler 2 – Buys crops from the farmer.
- Transporter – Transport crops between locations
- Retailer – Buys crops from wholesalers.
- Regulator – Controls the quality of other organizations and provides quality certificates.

B. Chaincode

The followings explain details of the chain codes.

- Price and private data negotiation between farmer and wholesaler.
- Price and private data negotiation between wholesaler and transporter
- Price and private data negotiation between wholesaler and Retailer.
- Crop transferring

1) *First smart contract (S1):* Following common functions will be available for seven organizations on smart contract 1.

   a) *Farmer:* Access to the following functions.

      - Record Crop
      - Query Demand
      - Update Demand
      - Update Price

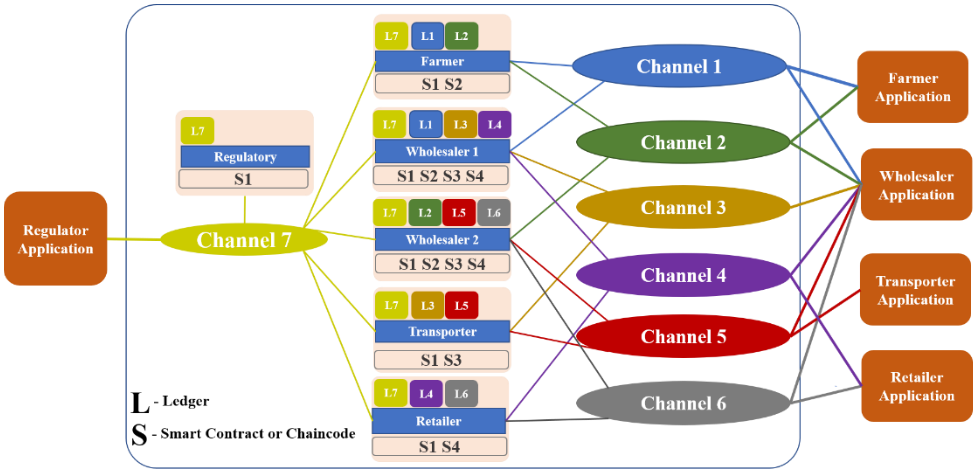

Fig. 2. HF based blockchain network for crops supply chain

b) *Wholesaler:* Access to the following functions.

- Record Demand
- Buy Crop
- Update Demand
- Query Crop
- Pay Transport

c) *Transporter:* Access to the following functions

- Query Transport
- Record Transport
- Update Transport
- Pickup Demand

d) *Retailer:* Access to the following functions.

- Buy Crops
- Mark Purchase
- Query Crops

e) *Regulator:* Access to the following functions.

- Query Farmers
- Query Wholesalers
- Query Transporters
- Query All Crops

2) *Second smart contract (S2):* Mark price and private data between farmer and wholesaler.

3) *Third smart contract (S3):* Mark price and private data between wholesaler and transporter.

4) *Fourth smart contract (S4):* Mark price and private data between wholesaler and retailer.

C. *Channels*

- Channel 1 – Price and private data negotiation between farmer and wholesaler 1.
- Channel 2 – Price and private data negotiation between farmer and wholesaler 2.
- Channel 3 – Price and private data negotiation between wholesaler 1 and transporter.
- Channel 4 – Price and private data negotiation between wholesaler 1 and retailer.
- Channel 5 – Price and private data negotiation between wholesaler 2 and transporter.
- Channel 6 – Price and private data negotiation between wholesaler 2 and retailer.
- Channel 7 – Crop transfer.

D. *Applications*

- Farmer application – Farmer will use this to execute the function defined above.
- Wholesaler application – Wholesaler will use to execute functions defined above.
- Transporter application – Transporter will use to execute functions defined above.
- Regulator application – Regulator will use to execute functions defined in above
- Retailer application – Retailer will use to execute function defined in above.

E. *Ledgers*

There are six ledgers defined in the solution and peers in each organization will use ledgers as follows.

1) *L1:* This ledger maintains data private to the farmer and wholesaler 1

2) *L2:* This ledger maintains data private to farmer and wholesaler 2

3) *L3:* This ledger maintains data private to wholesaler 1 and transporter

4) *L4:* This ledger maintains data private to wholesaler 1 and retailer

5) *L5:* This ledger maintains data private to wholesaler 2 and transporter

6) *L6:* This ledger maintains data private to wholesaler 2 and retailer.

F. *Example Message Sequence*

1) *Step:* Farmer records crop (the available harvested stock) using farmer app.
2) *Step:* Farmer updates different prices for wholesaler 1 and wholesaler 2.
3) *Step:* Wholesaler 1 buy the crop from the farmer
4) *Step:* System update crop as bought, price and make available for transporters.
5) *Step:* Transporter picks the demand and delivers the crop into location.
6) *Step:* Transporter updates the demand and marks the price in the ledger.
7) *Step:* Regulator is doing continuous monitoring and removes Transporter or wholesaler from the network if any misbehavior has taken place.

G. *Implementation*

This design involves other key components in HF such as MSP, Order Service, Policies, CA, etc. For implementation of this solution, a network configuration file (NCF) is created after identifying the network initiator. In this design, it is the regulator. NCF contains channel configurations, policies, chaincode details, peer details, etc. So once successfully implemented the solution needs to be tested properly to identify performance and functional errors. Based on the performance test result implementation can be considered to fine-tune the number of channels and maintain private data collections which minimize the overhead of channel administration and provide commit and query private data without having to create separate channels.

This solution is to involve more organizations who are indirectly involved with this supply chain. Such as fertilizer suppliers, agriculture instructors, field officers (Fig.3 below). Further, this solution can be enhanced by implementing a loyalty platform where organizations can give feedback to each other, and with the transparency and immutability of HF each can get quality of works and goods provided.

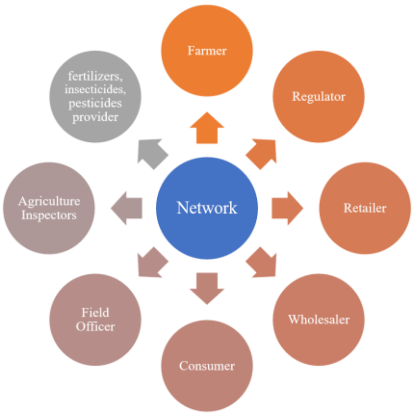

Fig. 3. Network contributors (Organizations) to enhance the solution

Another important factor is to enable an alerting system so that everyone will get alerts on various stages of the supply chain and it will help organizations give prompt responses rather than waiting till the last minute.

V. Result and Discussion

This section discusses how the above solution benefited to reduce food wastage and improve food quality in SL. This is a very powerful solution to align all the ad-hoc processes, entities in a very disciplined manner and build consumer trustworthiness while it supports saving food and reducing hunger.

A. *Responsibility of the regulator*

DLT platforms are primarily based on the feature of no central governance. HF also adopts that feature while allowing privacy over the data among the group of parties. All data visibility can be retained, only within certain groups, if desired. So, it would be good to have some common party who can track the activities of others to some extent. The regulator is the one who can perform such monitoring over the entire network. If the regulator is a representative of the government, it can be ensured whether the rules defined by the government are followed in this FSC. They can identify if something goes wrong within a channel or a PDC and take action against it. For example, if a transporter uploads a nice photo of transporting food even if it was improperly packed it can be notified by the farmer or the person accepting the transportation. Then they can add their comment or complaint to the system. Then the regulator can view those and warn the transporter. If it continuously happens from the same party, the regulator can remove them from the network. Regulators can also issue certifications to the involved parties throughout the chain which will be visible to others. It provides an extra layer of trust other than the built-in trust we can get with HF. When actors of the FSC are getting certified, it will cause the system to be more robust and food quality also improves, also, reduces food wastage.

B. *Farmer to wholesaler transaction*

Farmers are the most valuable entity in this chain, the starting point would always be farmers. Once they join this network they have two options to start farming. The first option is, they can choose their own crop to grow and update the network with the same information. Another option is they can check the demand in the network and start growing crops by accepting the demand.

In option one, once a farmer marks that he is starting cultivation it will be visible to all parties in the network. So that agricultural instructors and fertilizers, insecticides, pesticides providers are notified by the network and they can start to provide required knowledge and supply required items on time till the farmer finishes growing crops. So, these organizations also need to update the network with information including images and details of provided fertilizers, etc. So this information is visible to everyone and no one can alter them due to immutability in blockchain technology. Regulators can do continuous monitoring to maintain the quality of the cultivating process. By working with the HF network in this way it can reduce a lot of issues farmers are facing in traditional harvesting which results in minimizing food crops wastage and improving the quality of the same.

In the second option, everything is similar, other than the farmer starts cultivation once the farmer accepts the already created demand by the wholesaler. Since all the farmers and wholesalers are connected with the network and because of the permissioned feature in HF-based blockchains, wholesalers will be able to provide demand to farmers in private channels at an agreed price. In this scenario, there is no visibility for other farmers and wholesalers about this transaction, but regulators, agricultural instructors, and other raw material providers will have visibility about the transaction but not the prices and private data. That is the capability of a well-designed HF-based FSC network. Anyhow in both options wholesalers will have well-managed high-quality crops to provide transporters and then retailers.

The diagram in Fig.4 explains a summary of what was discussed in option one above.

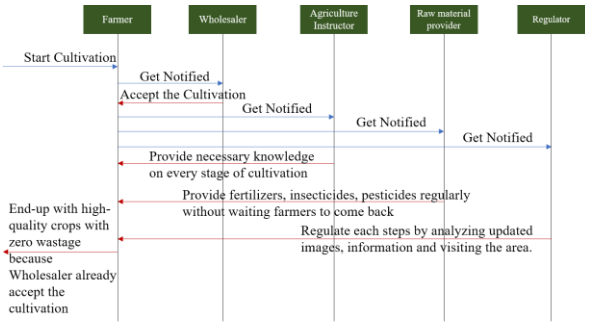

Fig. 4. Farmer to wholasaler transaction flow works in HF network

As per the diagram in Fig.4 farmers will have quality crops to sell to wholesalers who have already agreed on the price. But there can be two problematic situations where farmers will not be able to provide mentioned crops and wholesalers will not be able to buy the agreed crops. So, in both scenarios, the network can help to resolve this issue. Wholesalers can open the crop for another wholesaler who already joined the network. Farmers also can search for other farmers who are having similar crops and seeking to sell. So, the network itself connects each other to fulfill everyone's requirements. On the other hand, regulators can either remove such organizations from the network or give warnings if any repeated problematic situations occurr.

C. *Wholesaler to transporter transaction*

This section discusses how the wholesaler and transporter are involved with the network to maintain the same quality maintained by farmers and wholesalers to reduce food crops wastage. Once the wholesaler is ready with the crops, the system is updated with the same information, and transporters are alerted. In this case, the wholesaler will have a choice to update a particular transporter in a private channel or visible the transaction to the entire transporter network. But in any case, the regulator is notified with transaction information except prices and private data. Then the most important part is how the transporter packs, loads and unloads the crops. Transportation plays a crucial role in maintaining crop quality and freshness as much as possible. So, regulators need to play a vital role here because transportation needs to be closely monitored. So, the transporter's responsibility is to update the network with how they pack the crops and load the crops into vehicles. In this case images and videos, evidence is mandatory to update the system with geolocation tags. The regulator's responsibility is to remove transporters who are not following standards or not providing evidence to the system. Because of the immutability of HF-based networks, this information cannot be altered and that will build trust among the network members. On the other hand, transporters try to do their best to maintain the quality of transportation, otherwise, the organization's reputation gets damaged since it will be visible to the other parties on the network (transparency). Once transportation quality is maintained food crops' quality will not be damaged till it is provided to the wholesaler's storage location or retailer and food wastage will be minimum when considering traditional food transportations where sacks are not properly packed and loaded while in transition. The diagram in Fig.5 demonstrates the summary of this.

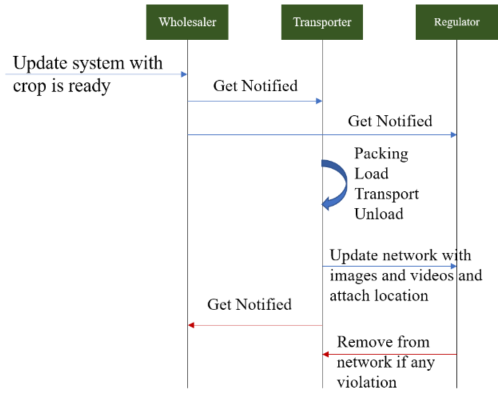

Fig. 5. Wholesaler to transporter transaction flow works in HF network.

D. *Transporter to retailer and consumer transaction*

Though the network controls food wastage up to transportation, there can be various reasons that food gets wasted due to various reasons such as poor storage and poor maintenance from the retailer end. If the Retailer did not receive the crops in good condition, they can update the network with status which will notify other members in the network. Because of that transparency, transporters will be careful on handling crops. Retailers need to update the network with how they keep crops in the market and these updates need to be monitored by regulators to identify unhealthy processes to reduce food wastage and increase consumer satisfaction. They also can remove retailers from the network if they are not doing a good job. The diagram in Fig.6 demonstrates the summary discussed above.

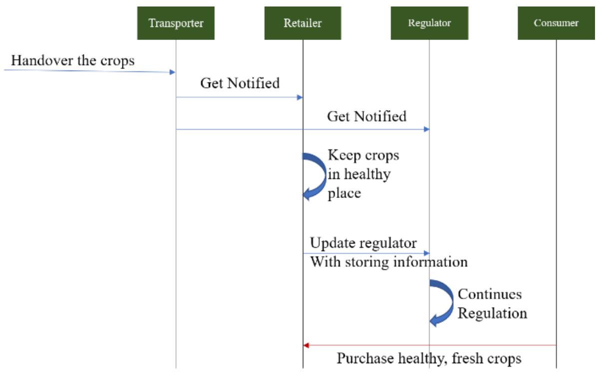

Fig. 6. Transporter to retailer and consumer transaction flow works in HF network.

E. Practical challenges

As crops are grown seasonally, there can be significant time gaps between supply and demand, which can lead to changes in market demand, making it difficult to enter into long-term contracts, and so on. As the number of farmers and wholesalers connected to the system increases, those factors may change further. Farmers and wholesalers can then identify their behavior patterns as they mature from the system and adjust their trade. Such factors can be further evaluated once the system is used inthe particular context.

Another challenge that might be faced when a technical solution to a problem is introduced to the non-technical people is, how far they will accept that. The protagonist here is the farmer who may deviate from that technical acceptance. Farmers rely more on traditional methods especially in developing countries [44]. So, the farmers are provided a simple mobile application with a user-friendly interface while hiding the technical complexity. Although, in the initial stage there can be little denials, once the farmers or other participants identify how far they can get benefitted, the same will attract them towards this solution. Especially when it comes to farmers, very few people in countries like SL ever think of becoming farmers because of the uncertainties associated with it. Most people want to do a professional job. But nowadays those of the younger generation are the ones who use smartphones. Therefore, when technology is involved in traditional farming, they may also be interested in it. There may be some similarities, but the behavior of farmers can vary according to their country. Therefore, a country-based survey can be conducted for the technical recognition of non-technical individuals and the results can be used to improve the solution.

The practical implementation of this research can be further evaluated using qualitative and quantitative methods and enhance the HF based FSC towards the maximum reduction of food wastage in SL. Eventually, consumers can be satisfied with quality crops which came through a process where transparency, trustworthiness, and immutability played a major role.

VI. CONCLUSION

There is a lot of research and implementation based on how to use DLT in FSC. Though this has great value, still organizations are having a low tendency to join with such chain networks. This is mainly due to transparency where all the network members will have visibility on each one's data. But HF is playing a vital role to break that concept where organizations can make private channels to hide data when they need privacy. At first glance, the HF architecture looks complex as a lot of components are associated with it. Once the components are properly identified, wecan easily handle an HF network the way we want. According to this study, various parties can join the HF-based FSC and it presents how to actively contribute to minimizing food crop wastage while maintaining the privacy they want. Though there are a lot of discussions on DTL-based FSC none of them have focused on reducing food crops wastage while keeping data privacy in each party. Throughout this research, we focused on how everyone can contribute to reducing food crops wastage on FSC after analyzing the current ad-hoc process in SL, how the crops come from farmers to end consumers. Also, literature on HF technology is well supported to resolve practical problems that arise while implementing such FSC. Not only inSL if any country is having such an ad-hoc supply chain, from farmers to consumers, they can use this analysis to support the development of HF-based FSC to reduce food wastage and finally reduce world hunger.

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