Optimizing Industrial Supply Chain with Blockchain

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Abstract

Supply chain management is the essential part to enhance the coordination, which refers flow of product and exchange of associated information among different actors of supply chain network. This flow have primary importance as product is modified and transform as it passes from one actor to other. Supply chain faces many issues such as: traceability, food provenance, food contamination and quality control. Global food supply chain network have multiple operating procedures because information stakeholders spread over multiple continents which results into and regulators asymmetry hinders to track food incidents and trace product. Detailed literature review on challenges of food provenance, current safety regulations, issues of food-borne and contamination, blockchain based model development that makes stakeholders accountable if some issues occur. Secondly, IoT scanning points enhances traceability, identify food items and record food contamination incidents. Proposed blockchain model is implemented using Hyperledger Fabric, which highlights benefits over conventional systems. This dissertation is also describes future research areas such as: private channels in blockchain, blockchain based model of food waste management, lightweight security algorithm for Internet of Things (IoT), to digitally sign transactions.

Dedication

Dedicated to my exceptional parents and adored brother whose tremendous support and cooperation led me to this wonderful accomplishment.

Certificate of Originality

I hereby declare that this submission is my own work and to the best of my knowledge it contains no materials previously published or written by another person, nor material which to a substantial extent has been accepted for the award of any degree or diploma at NUST SEECS or at any other educational institute, except where due acknowledgement has been made in the thesis. Any contribution made to the research by others, with whom I have worked at NUST SEECS or elsewhere, is explicitly acknowledged in the thesis.

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Contents

List of Figures

List of Tables

List of Abbreviations

IoT	Intenet-of-Things
BC	Blockchain
FSC	Food Supply Chain
SC	Supply Chain

Chapter 1

Introduction

Food consumption in Pakistan is increasing day by day as population growing. According to survey conducted in 2016, food consumption arises from fifty thousand tons to sixty thousand tons in past ten years [1]. Graph 1.1 demonstrates the rate of food consumption.

Customers consume food products on the bases of trust; they have on supply chain actors who produced, processed, transported, stored according to internal and government regulation policies. Traditional food supply chain is complex, fragmented, in which products flow through an extensive network, ranging from producer to consumer. Stages of producing, processing, retailing and storing are discontinuous. So, food regulation on traditional supply chain is difficult and conduct periodically after time-to-time. In case of global supply chain, food inspection is often untrustworthy because of uneven technology distribution. Many incidents happened due to this reason for example, donkey meat sell in all Pakistan in 2015 [2], in Karachi two children died by eating expired meat in 2018 [3], horse meat sell in Europe

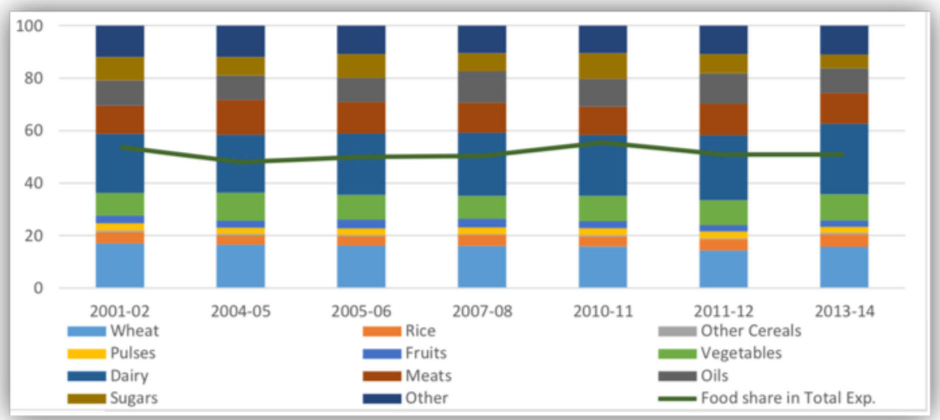

Figure 1.1: Aggregated Food Consumption Rate at National Level [1]

in 2013 [4], and in 2017 US stop importing meat from Brazil because of inspection team took bribe [5]. These incidents demand to make supply chain more transparent so customer can make the supply chain actors accountable. Consumers have not any authenticated process to get healthy food products as advertised but they can't show that their choices as they don't have any alternatives. Customers don't have trust on supply chain actors due to information asymmetry and fragmented nature of supply chain as research conducted by Lloyd's Bank showing [6]. Customers need authenticated food products from verified resources and big food producers and retailers realized the need of it. But in Pakistan, customers can't able to trace their food items back to producers as food companies take the risk and trust on actors, dispersed over the Globe. According the people's need around the globe, word's giant organizations i.e. IBM, Walmart and Tsinghua University conducted the research to trace food products during flow around the supply chain, store supply chain information on the Blockchain so that product can easily be traced by end customers [7–10]. Traditional Silo Databases are not optimal solution for fragmented nature of supply chain as it provides forgeable trust on third party and data can easily be tempered. By this way, products can be tracked between different stages but can't be traced back to the first step. Even hash integration with databases make it inefficient and increase the latency rate during data fetching when user request for specific type of information. Due to imbalanced supply and storage strategies, weather, environmental and exploited labor conditions would affect the food which will start contamination of the food. End customers should able to trace products through all stages of blockchain with minimal effort. To provide food provenance, blockchain provides the decentralized solution to improve the immutability, integrity, efficiency, provenance, trustless while its alternative solution to provide data and transaction transparency is to depend on central authority. But customers are always use this kind of solution without knowing the ramifications and potential risks of it because centralized solutions are not able to identify counterfeiting products and communication among supply chain actors.

1.1 Motivation

Blockchain integration with food supply chain helps to become the paperless transaction records, transactions traceability, visibility enhancement, remove intermediaries and make the communication less expensive and efficient. Blockchain solution is the most secure, provides high level of digitization, which enables end-to-end customer traceability to identify counterfeit products to enhance customer satisfaction, limit the food contamination and automate the food supply chain. Internet-of-Things (IoT) and sensors uses to gather the real-world data that effects on food supply chain and help to increase tracking of product among supply chain, end-to-end traceability.

1.2 Problem Definition

These days, food supply chain are centralized, large, complex and difficult to manage. Traditional supply chains are challenging to implement rigorous end-to-end checks for quality and compliance because stakeholders, customer unable to track and trace the products back as they have limited information.

1.3 Objective and Research Methodology

This research presents the following goals:

- To offer blockchain-based solutions for industrial projects
- To promote sensors and electronics industry in Pakistan
- To provide indigenous and economical security solutions to the local industry
- Traceability
- Transparency
- Low-Cost Solution
- Blockchain based IoT Solution

- Rich-Feature Application for Users

1.4 Thesis Organization

This section of thesis presents thesis organization, where chapter one describes introduction of the work, with problem statement, project's motivation, objective and research methodology while chapter two summarizes background of supply chain and blockchain as it's required to understand underlying thesis. Chapter three reviews relevant research papers and related projects to presents state-of-the-art. Chapter four discusses the proposed solution to the stated problem statement and chapter five shows the results of proposed solution and compare it with traditional solution.

Chapter 2

Background Study

This chapter presents brief overview of background, food supply chain and blockchain. all concepts related to thesis are written in this chapter. Initially, issues of traditional supply chain is explained in sub-section and sub-processes regarding every stakeholder is described. Then overview of blockchain is discussed in detail and underlying platform of Hyperledger fabric and its architecture illustrates in last section.

2.1 Food Supply Chain

Traditional food supply chain is complex, extensive, difficult to manage, opaque across different participants across the globe. Consumer buy food product on the base of trust which flow throw complex network from manufacturer to retailer. Transportation is the key stakeholder that serves to link one participant to other. Compliance assurance is difficult to achieve in fragmented supply chain when participants communicate remotely. Stakeholder in food supply chain includes manufacturer, supplier, distributor, trader, retailer and customer. Government needs to make policy and ensure food standard to ensure quality, sustainability, security and compliance so that every stakeholder needs to follow. Food Inspector is responsible to manage, supervise and ensure compliance in supply chain.

2.1.1 Food Producer

Agriculture sector is always important factor in Pakistan's economy from the independence year until now as shown in 2.1. According to GDP from agriculture in 2017, 2284561.00 PKR million economy of Pakistan depends on agriculture and food production sector [11]. Many sectors depends on agriculture and food production sectors as food, beverages, fishes, fruits, textile, apparels, sugarcane, rice, grains, spices and livestock. Agriculture contributes 18.9% in GDP and absorbs 42.3% of labor [11]. Now a days, food supply chain move products between continents, so this process should be more transparent, safe, secure, traceable and trackable. In agriculture, starting phase of food production is more important because food fertilizer, seeds, machinery and labor are vital part of initial point. While in milk and meat sector, food to animals are more important that is also co-related to agricultural part. Any issues on initial stages can bring severe consequences in food quality and availability. Next stage is to produce the food by farmers or get milk or meat from milkman or butcher; this stage plays central role

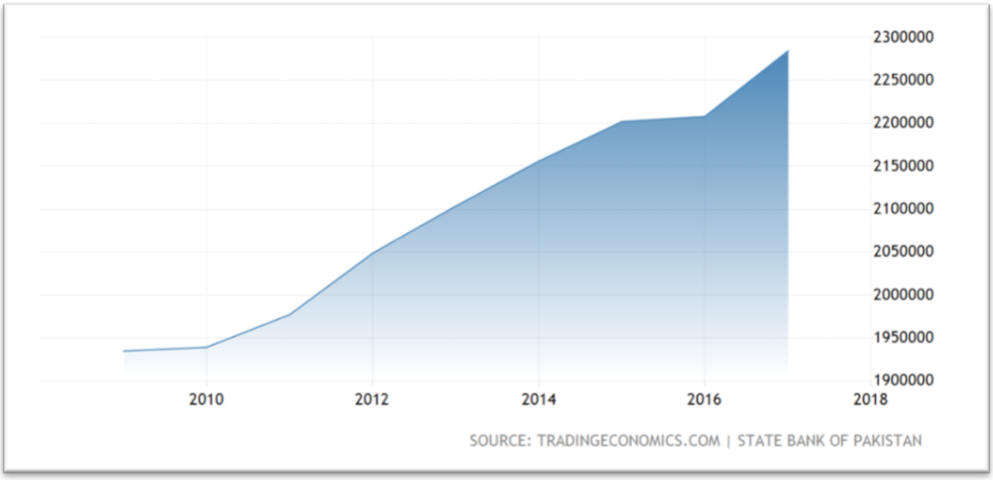

Figure 2.1: Pakistan's GDP – Agriculture [11]

in food supply chain as food produce or managed on this step. Modern agriculture methods such as, greenhouse farming, soil sensors and usage of LED light instead of sunlight, demands more traceability and trackability to ensure healthy food methods and compliance if are there methods are healthy for consumer?

2.1.2 Food Manufacturer

Food manufacturers are food processors, who take the raw food and transform raw food into food product which is purchased by customers. Food processing is important to preserve food from germs, add more nutrition into food and kill bacteria which can spoil food. Processing on vegetables and fruits are much easier as they just need to make slices of it while processing on milk and meat are difficult product as temperature processing is require. Processing includes packaging of food, transit and ensure food quality during this step. In order to make the food lifetime longer and export food to different countries or continents, food processors need to freeze, process, pack and refroze the food. In this process, quality assurance and compliance are more important. Meat and fish processing is somewhat different than vegetable and fruit processing. Raw meat doesn't have some structure to track the information in supply chain as meat supply chains are not structured to ensure food provenance and verify sustainability. This stage requires standard and policies to maintain quality of food during processing, maintain temperature during transit or in logistic to move between continents. Other food processors could be hotels, airports, hospitals, restaurants, airlines or takeaway services which transform raw food into consumer's need.

2.1.3 Food Retailer

Retailing is most important part of food supply chain as it flows cash by selling the product to customers. Retailing is the process has many participants such as, distributor and wholesaler who distribute the products from manufacturer and sell into retailers; wholesalers buy products in bulk and sell them to customers and retailers. In case of small retailers, distributors are responsible of product movement from one supply chain actor to other, which manage food perishability and quality of food. But large retailers own their distribution center that cope with transportation cost, product movement and food fragility and compliance. Manufacturer is responsible to apply barcodes, labeling and product packaging but retailer is only conscientious to make product available on shelf for customers.

2.2 Blockchain

Blockchain is 5th disruptive paradigm which predecessors are Internet, mainframe computers, etc [13]. Blockchain is distributed ledger that used to get rid of intermediaries to trust on. Blockchain started in 2008 by Satoshi Nakamoto by designing cash flow system, in comparison with traditional banking system [14]. Blockchain presented new technology by distributing information on multiple computers, not copies data on all computers. Cryptocurrencies also uses blockchain concept e.g. Bitcoin, Litecoin, Ethereum etc. Blockchain promotes immutability, data on the blockchain can't never be deleted. Data stored on blockchain is truly public and verified. Verification is ensured by cryptographic assurety by getting hash of previous block and append with next block. Every node has public and private keys that made possible a transactions. A transaction contains information other than public/private key pair, such as sender and recipient addresses, hash of previous transaction, asset information and transaction number. Asset could be the thing which ownership could be changed or buy or sell between actors of supply chain. Blockchain provides immutability because every transaction has hash, of 256 bits length, of last transaction. So that any changes in transactions can easily be detected. Hash never be the same as public key of every user can never be the same. Number of randomly collected transactions makes the block and every block also have the hash of previous block. Miners verifies the transactions and senders by brute force the hash of block, this process is called mining. Miners are facing the difficulty level by winning the cryptographic hash value by verifying thousands of transactions. By the

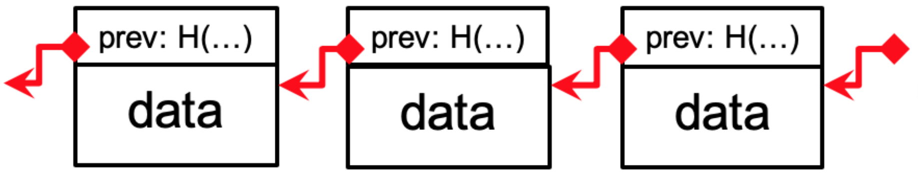

Figure 2.2: Blockchain

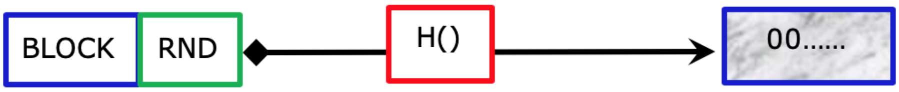

Figure 2.3: Mining Process

process of mining, miners get reward for their work. Consensus algorithm is used to choose miners among thousands by using consensus algorithm, for example Proof of Work and Proof of Stake as Bitcoin and Ethereum respectively. Miners need computational power for mining so they get the reward for it. Difficulty level changes with the time by updating the nonce that fluctuate the hash value, eventually. This is the process of mining the new crypto-currency as a reward. Ethereum blockchain based on the rules agreed by network participants via smart contract. Smart contract is shared piece of code, distributed on the network. In Blockchain, participants never trust on single entity of the system. So this is the most optimal solution for managing the fragmented supply chain. With the help of blockchain, every record is sync on entire network and higher processing power is not required by this type of solution because every participant contributes its computational power.

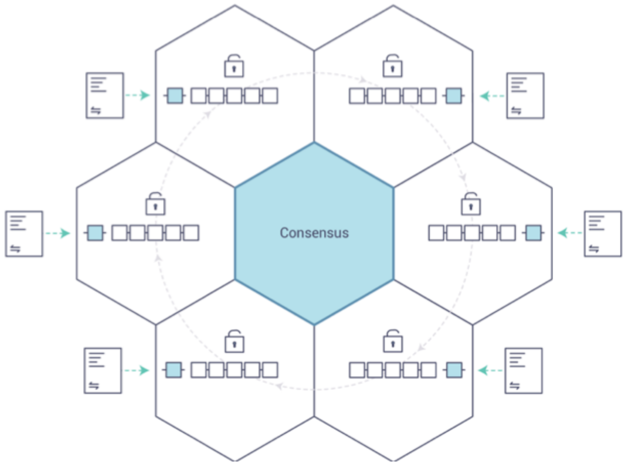

Figure 2.4: Consensus Mechanism [15]

2.2.1 Hyperledger Framework

Hyperledger framework is open source and IBM initiated this project as Hyperledger Fabric, for the project collaboration with Tsinghua University and Walmart. Under the umbrella of Hyperledger framework, eight projects are initiated. Advantage of this project is to use minimum usage of energy while making consensus, in contrast with Bitcoin. The process of keeping the network synchronized and update called as Consensus mechanism. In this mechanism, participants make sure to approve every new transactions and update the ledger in the same order, as shown in 1.1. Hyperledger Fabric uses consensus mechanism such as: Solo, Kafka etc. Kafka is a fault tolerant approach. In case of Hyperledger, consensus mechanism works on transaction level, only transaction nodes have to agree, not all nodes need to involve in consensus mechanism. Only transacting parties need to participate in consensus mechanism. In fabric, nodes assumes roles and tasks in order to accomplish consensus mechanism. Three types of nodes are participating in consensus mechanism that are: peers, orderers and clients. Clients are end users which initiate transactions, while query transactions while orderers orders the transactions and send to peers. Peers are the entities who maintain the ledger and sync all transactions. Peers used to endorse transactions by checking necessary conditions for transactions according to requirements of Hyperledger Fabric, from number of ordered transactions [16]. Kafka is consensus mechanism of Hyperledger Fabric. Kafka is distributed, append-only ledger and fault-tolerant and have O(1) complexity in worst cases. Kafka supports multiple orderers to order thousands of transactions to manage fault-tolerance and efficient. Drawback of Kafka is that it's not use to detect malicious nodes of the system and if you need higher throughput, >1000tx/sec, then Byzantine-Fault-tolerant consensus mechanisms is better option [16]. According to this project, Hyperledger Fabric has some plus points which are written as following:

- Immutability promotes by consensus mechanism, Kafka
- Hyperledger supports private and permissioned Blockchain, and secure the organization's transactions from public
- Append-only ledger helps to secure all transaction history
- Smart contract use to process end-client transaction requests

2.2.1.1 Hyperlegder Fabric

Hyperledger fabric has distinctive framework and developed before Ethereum framework [17]. Chaincodes can be written by using any language such as:

GoLang, Python, Java Script etc. but majority uses Go language. Hyperledger Fabric provides the functionality of easy implementation of supply chain management. This type of blockchain is used to record all type information among supply chain actors as product moves through one to another. Kafka use to randomly selects the transactions to make the block and have ability to tolerate the faults which makes it more feasible for large networks. This version of Hyperledger enables tracking and tracing for every cases e.g. one-to-one, one-to-many, many-to-one, and many-to-many. It presents all cases in which one-to-one sensor enabling is not the cost optimal solution, for example milk from dairy farms to end customers and meat from butchers to end customers.

2.2.1.1.1 Terminologies of Hyperledger Fabric Basic terminology of Hyperledger Fabric are written as following [18]:

- **State** – State is current key-pair value to represent asset. The change in state recorded as transaction over ledger. Peer nodes are maintain state and set of keys (K) used to map elements with the set of **V x N**, where V is set of values and N is an infinite ordered set of version numbers [19].

- **World State** – World state used to store the current values of attributes of business network in a unique ledger. It helps to use the current value of an object when a programs require, otherwise program needs to traverse whole blockchain to retrieve current value of an object.

- Nodes – are communication entities of Blockchain. Following are types of nodes:
  - **Peer** – Peer maintains the copy of ledger and have ability to commits transactions.
  - **Endorser** – Peers who endorse the transactions as valid or invalid is called as endorsers.
  - **Orderer** – Orderer provides the communication channel to peers and clients to enable communication.
  - **Client** – are the end-users, which needs to connect peers in order to communicate with the blockchain.
- **Transactions** – When change in state of asset is noticed then a transaction is made and recorded on ledger. There are two types of transactions as following:
  - **Deploy Transactions** – This type of transactions is made by installing new chaincode on Hyperledger node. Deploy transactions take parameters from chaincode.
  - **Invoke Transactions** – Invoke transactions fetch information from recorded data over Blockchain. This type of transactions use the functions of chaincode perform operations on Blockchain.
- **Ordering Service API Policy** – Peer uses the ordering API to communicate with the orderer. Methods of ordering API is broadcast, called as "blob". This ordering API broadcast the message over the channel and use previous hash, sequence number and message. There

are two mechanism for ordering service: Safe method guarantees consistency while delivery guarantees by live method.

- **Endorsement Policy** – defines the policy to validate transactions. When chaincode installs on blockchain, it provides the set of parameters to meet by transactions; these conditions also called endorsement policies.

- **Writer Policy** – These policies specifies which users submit which kind of transaction to a particular channel. Writer policy define at the time of channel creation.

- **Ledger** – Ledger is associated with state and transactions. Ledger records all transactions on the Blockchain by the nodes. Ledger records all valid and invalid transactions and have key value related to assets. Unique feature of Ledger is that it gives the functionality to provide unique ledgers to each channel. All nodes in the channel have each copy of ledger. Orderer makes the block of transactions and compute hash chains of blocks. Peers and orderers maintains separate copies of ledger. Peers ledger maintains the invalid and valid transactions identified by BitMask while the ordered ledger only have valid transactions.

2.2.2 Challenges in Blockchain Standardisation

Blockchain adoption faces standardization problems as different blockchains have different consensus mechanisms, policies, programming languages, transaction validation parameters and set of permissions and privacy [20,21]. Standardization helps to integration of applications by enabling cross-blockchain transactions, interconnectivity among different technologies, which helps to overcome interoperability problem. Regulators starts to put their efforts to make some standards for Blockchain as Blockchain is buzz word for 2018 as 17 US legislatures put effort to pass bills related to Blockchain. But notional nature of Blockchain makes the regulators and researchers uneasy [22]. As initial coin offerings (ICOs) banned by many developed countries such as: Chain, Korea, US because it used for frauds. In case of Smart Contracts, Blockchain regulators are uncertain. There are also few experts who have enough training and excellent skillset is also significant difficulty to adopt this cutting-edge technology to adopt. Standardization requires to mitigate the interoperability problems among networks, integration with Blockchain.

Chapter 3

Literature Review

This chapter covers details of analysis of food traceability integrated with Blockchain. Mainly this chapter includes detail about what the food traceability is?, how blockchain helps to trace the food from customer to manufacturer, technologies used with hardware and software, all driving forces for food traceability, advantages of supply chain integration with Blockchain, ontologies for new technology adoption. This chapter enlightens the issues about adoption of blockchain to manage and trace the food supply chain.

3.1 Drivers for Food Traceability

Most authors define food traceability as "the ability to follow the movement of food within supply chain" [23]. Three components are (i) tracing as backward follow-up of product while (ii) forward follow-up is tracking, whereas (iii) this process provides the product history associated with product movement within food supply chain. There is no standard definition of food traceability as ISO 8402 defines “the ability to trace the history, application, or location of an entity using recorded identifications” [24]. Many authors tried to differentiate logistics traceability, physical movement, and qualitative traceability as food quality and consumer safety. These type of definitions may not explain the concept well as product move within supply chain along with logistics. Many researcher indicates traceability is the improvement factor regarding food quality but rarely connected with business development and logistics improvement [25]. Literature missing the concept how logistics information is playing vital role for food supply chain to manage the food contamination. New literature enlightens the concept of integration of sensors and IoT devices installed at every checkpoint of food supply chain to capture the real-time data of factors that affects the food supply chain to trace the supply chain continuously. In a blockchain network, every product becomes an asset, and every IoT update serves as transactions performed on the asset. Thus, with a unique product ID, any food product can be traced and tracked for quality assurance and logistical activity. Food traceability studies started for more than two decades which describes some food supply chain drivers that is written as following [26–29]:

3.1.1 Technologies in Food Supply Chain

From the past decades retailers put their efforts to create omnichannel environment for its customers to provide efficient environments. This way, retailers provide multi-channels for online trading, stores and provide online collect points to provide the ease to customers. Retailers are experimented and de-

Major Concerns	Driving Forces
Lack of Regulations	Introduction of new food safety legislation is needed to maintain market power and generate revenue.
Lack of Safety and Quality Measures	• What policies do we need food contamination? • Definition of safety hazard need to tackle food safety crisis • Value preservation and value addition require in food supply chain
Social Concern	• Contaminated food cause to rise health concern, eventually decline consumer confidence. • Quantity-oriented vs Quality-oriented • Consumer needs history of product, e.g. genetically modified organisms (GMO) and non-GMO • Awareness increases in consumer about health, quality of food, nutritional values of food.
Economic Concern	• Food Quality Improves • Better Market Access • Food Prices stables for owner • Food companies makes the economy better
Technological Issues	Advancement in technology encourages traceability

Table 3.1: DRIVING FORCES IN FOOD SUPPLY CHAIN

veloped an efficient, responsive and transparent distributed system. Later, actors of food supply chain used RFID, CPFR and EDI to uniquely identify items, enhance traceability and automate all supply chain processes [30]. Literature survey enlightens that technology in supply chain boost the quality assurance, provide more security and method of uniquely identification. In past years, product can be identified by using paper, RFID tags and electronic systems, e.g. databases. In meat industry, barcodes, microchips, RFID tags affix on animals, RFID transponders injected into animal's ear, bio chemical markers or voice recognition system integrated with Internet of Things (IoT) [31,32]. Automated supply chain helps customers to adopt technology, enhance their trust on supply chain actors and provide good quality and fresh food products. Big giant organizations are working on automate whole supply chains by using cameras, sensors and intelligent AI software to charge the customers and they can choose the products from stores by themselves. This idea is applicable for bakeries, where manpower isn't require much as Amazon go store, in Seattle, Chicago, Illinois and San Francisco, doesn't have cashiers and checkout lines [33]. Now 22 companies and growing number of companies set up their systems with Blockchain to manage assets, identities and authenticate critical documents with the help of distribute identity management over peer-to-peer network [34]. Very few companies are working on blockchain to improve product provenance and trace the product back. These companies are: Everledger, Provenance, Hijro, Skuchain, QuickBook and Blockverify, which verify products through blockchain like diamonds, seafood, pharmaceutical drugs and expensive hands bags [35–40]. In [41], authors proposed the system which take advantage of logistics information to improve the food supply chain operations and track where the food were contaminated. Presently, food supply chain operates on centralized system but this tradition automation system is optimal solution for trusted environment where actors trust each other or take services from third party. This type of systems collect the data when products reach at the level of distribution and retailing but the user can't make the all actors accountable as shippers, manufacturers and supplier and their information collects in database silos as excel sheets or on paper. But these type of systems, require data security, data sharing, data capturing algorithms and permission rights to view and share the data.

3.1.2 Advantages and Issues of Implementation

Food traceability system portray many advantages such as financial benefits and profits for companies, people put their more trust on supply chain participants, social benefits, provide more ease for authorities to track every data, participants put on blockchain [42]. Food traceability helps to minimize the issues of quality, food contamination, food borne, similarly customer complaints would be reduced and improve customers satisfaction level. This type of systems supports regulators to pin point the hazardous food product and detect counterfeiting project that eventually reduce the vulnerabilities on every stage of food supply chain [23]. Companies can use these systems to reduce the information asymmetry, and reduction in logistics, procurement or inventory management as every actor put the data of every transactions on Blockchain or system in more sophisticated manner that use to track the item.

Because availability of data, about every actor, encourage the community to understand the patterns which helps to create applications to provide more safety and security in food supply chain and mitigate unsustainable sourcing practices. Barriers to opt the technology is capital, operational cost due to which small businesses aren't agree to adopt new technology and willing to take the risk. This type of systems are not well designed, not user friendly and more complex for novice user. Immense paper work, operating mechanism and operating systems to operate ERP systems required special training to make automation hard for every level of supply chain. Above mentioned barriers are more challenging when this project will deploy on a large scale for multiple participants of food supply chain. IoT and sensors play important part in food traceability system that needs special food packages to integrate data capturing devices is notable challenge in establishing IoT architecture upon which blockchain thrive. Many issues face while tracking of upstream supply chain stages of production and harvesting when product isn't packed and raw, raw milk and raw milk. [43] proposed ontology based blockchain model integrated with IoT, use for data capturing and presents there are no common standards of food supply management that can be used to follow on every stage of supply chain. While in 2018 a paper proposed the blockchain adoption with Unified Theory of Acceptance and Use of Technology that considers influence of certain factors such as: environmental factors, end-system behavior, end-user acceptance and behavior, scalability and adoption of new technology [44]. [45] presents a layer approach to adopt the supply chain interaction complexity to adopt blockchain and issues while IoT integration to manage and capture real-time data. This paper presents the comparison of blockchain based system with databases by using stimulated data.

3.1.3 State-of-the-Art

In 2018, IBM, Walmart and Tsinghua University started the pilot research to track the pork and mangoes supply chain. They started this study to make the interaction transparent among the supply chain actors but this project isn't open for consumers to trace the product back to know the product history [7–10]. Authors presented extensive study on logistics in supply chain in [45]. Authors proposed model for logistics in terms of privacy policies, transportation policies. Paper explained how logistics and supply chain actors can work together because raw material could not transform into product without logistics. In [46], authors proposed the blockchain model to enhance manufacturing supply chains in the composite materials industry while authors reviewed current status of blockchain technology, discussed potential benefits of blockchain for manufacturing supply chain and proposed model for it in [47]. This paper described agri-food supply chain traceability system based on blockchain and RFID technology and presented the building process of this system with low cost technology. Proposed solution realized the traceability with trusted information which would effectively guarantee the food safety and authenticated data from every actor [48]. EU funded projects are started in 2014 that aims to provide food integrity, authenticity and security to every stakeholder on each step of food supply chain [49]. This project presented their prototype on olive oil, seafood, and sprite drink supply chain. This system developed warning system to predict food risk by using food patterns. Another EU funded project, named as SeafoodTrace: Intelligent Traceability Platform enabling full transparency in the Seafood supply chain, provided the transparency at every level of food supply chain by using anti-temper smart labels, temperature sensors, and RFID tags to uniquely identify the products and integrate their data on blockchain to enable the immutability [50]. Comparison between traditional system and modern blockchain enabled system is absent in literature.

3.1.4 Food Safety Standards & Policies in Pakistan

Pakistan doesn't have any integrated legal framework for food but has set of laws that deals with food quality and safety standards. These laws are poorly enforced because of which minimum level of food safety and quality is achieved. Law named as Pakistan Standards and Quality Control Authority Act describe about regulations about food safety. Pure Food Ordinance 1960 amends the law of preparation and the sale of foods, which aims to supply fresh food to people in market to prevent adulteration while this law adopted by all provinces and northern areas [51]. But this law isn't applicable on cantonment areas, for these areas another ordinance is followed Cantonment Pure Food Act with no substantial differences in comparison with the previous ones. Pakistan Hotels and Restaurant Act regulate the rates, standards and follow hygiene standards to prevent the food contamination. But there is no automate food traceability system to make actors accountable who don't follows the rules [52]. Pakistan Pure Food Laws (PFL) provide the legislative framework but don't have any verification mechanism for meat and milk freshness. Animal Quarantine Department inspects the exported meat and products of dairy sector but they don't accountable upstream food supply chain actors. Pakistan Standards & Quality Control Authority is the national standardization body that are responsible for enforcement of standards. This body inspects and test products and services which includes quality, characteristics, perishability and specification of food items, which is good to human health [53]. In Pakistani system, both public and private organizations need food traceability systems to put more trust over their business and provide them financial benefits.

Chapter 4

Methodology and Analysis

Literature shows that from last decades, many technologies have been used in food supply chain but many of them integrated among all stages of food supply chain, as database silos making the traceability so difficult. This chapter presents model the current data architecture for food traceability by considering food outbreak dataset and propose the food traceability architecture based on blockchain and IoT devices. This chapter describes the advantages of proposed solution regarding efficiency, robustness and cost.

4.1 Food Borne in Pakistan

Food borne is root cause of illness in Pakistan, like other developing countries. Approximately half of cases cause due to supply chain actors doesn't meet food standard, introduced by supply chain regulators. Influential factors of Food borne are environmental, personal hygiene, improper storage and reheating of cooked items. According to survey, raw meat, milk and their

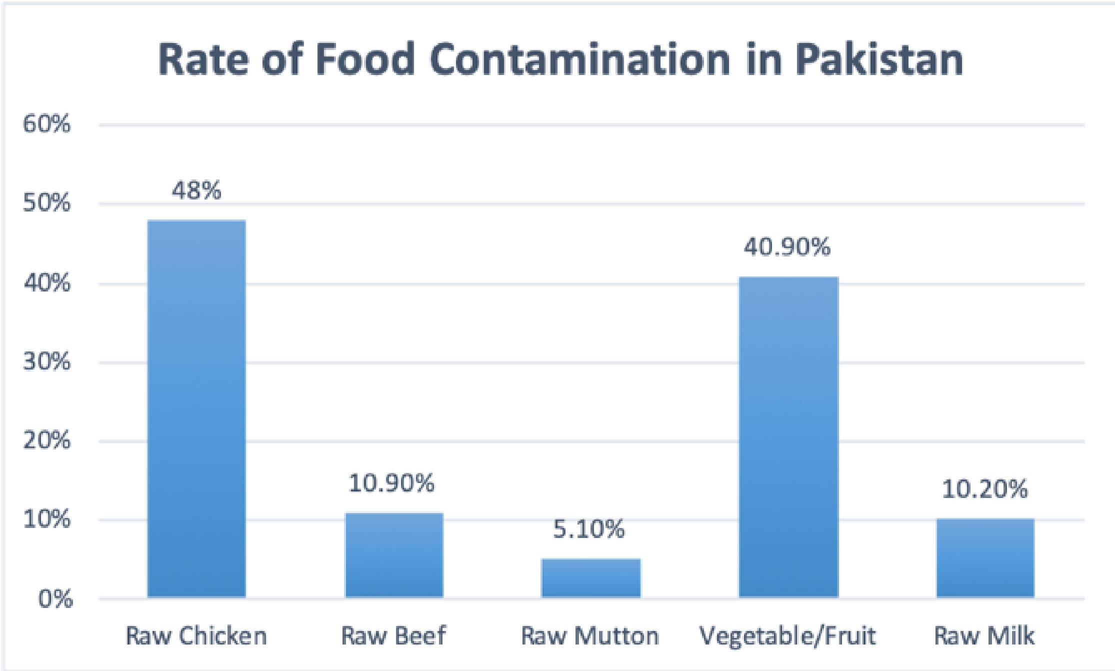

Figure 4.1: Rate of Food Contamination in Pakistan in 2016 [55]

products are more prone to contamination. [54]. Food contamination can occur because of certain factors such as: labeling issues in supplying phase, physical contamination, chemical contamination and microbial contamination during manufacturing due to temperature. Temperature and humidity is primary cause of food contamination that needs to be focused during freight management. 4.1 figure shows the meat, milk, vegetable and fruits products are more prone to contamination during processing stage and retailing phase. Food Borne causes death in adults and children, according to survey 1 out of 10 adult and 3 out of 10 children die because of this [56]. Following figure shows the highest number of deaths occurred due to contaminated food.

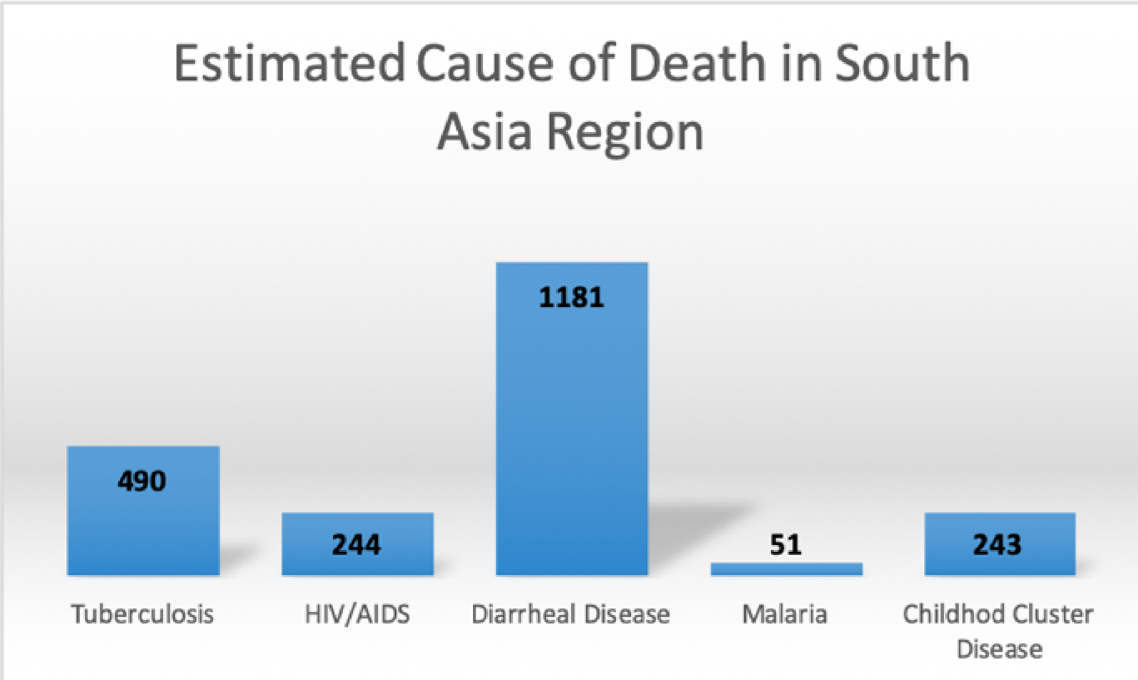

Figure 4.2: Estimated Cause of Death in South Asia Region [57]

4.2 Blockchain based Food Traceability System

Pakistan need food traceability system as no system implemented and running so fourth and no food regulations have been followed by supply chain actors. So, this thesis aims to propose a traceability system from farm-to-fork in this section. IoT devices use to record information of any event and real-time data about environmental condition as well. Every event record in the form of transaction on the Blockchain such as manufacturing of food product, product/asset information, movement of product, transfer of ownership, packing of product, storage and logistics. Food processor and manufacturer stage need many checkpoints to stop food outbreaks. Terms among supply chain actors have been written in smart contract that will be triggered when an event take place. Multiple transactions are batched in a block and necessary parameters are verified by transaction processor to include them in a block. Smart contract make the actors to play fairly as each participants digitally signed once they agreed on different terms of smart contracts. Every actor in food supply chain share every data to blockchain that makes visible to other actors and make information traceable from consumer to manufacturer; every minor detail of product is public for everyone. Each actor of food supply chain send the data to blockchain node which records over blockchain. Contract layer makes the communication transparent among multiple players and validates all transactions, checks transactions requirements, permissions of data view and consensus require to validate transactions of the ledger. Not any node join the blockchain the network without authentication by network admins. Permissions of data isn't similar to every actor of food supply chain that protects sensitive data from misuse. Every node of blockchain contain information of complete history of all validated transactions that is immutable and important factor for food quality system and identified food safety violations. Blockchain based model enhances the immutability, ensure quality of food and transparency among different layers of food supply chain. Following figure presents the design of blockchain based supply chain network.

4.2.0.1 IoT based Security Checkpoints

In [56], authors proposed the idea of embedding RFID tags on animal ear for tracking and traceability purposes. IoT devices helps users to track the ani-

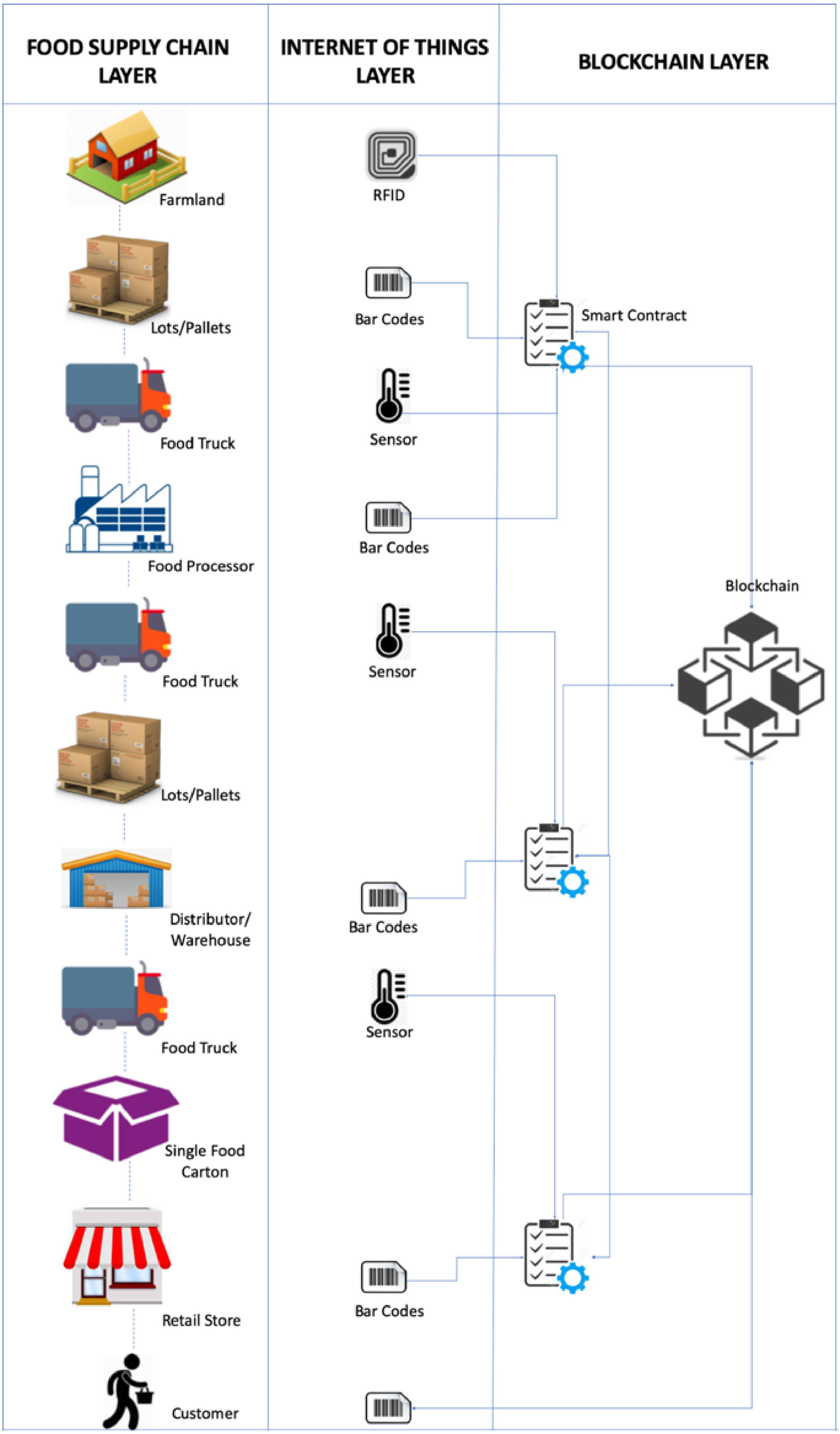

Figure 4.3: Blockchain based Food Supply Chain Network

mals and their product in the flow of supply chain network. This concept uses in blockchain based system to track the animal's health and other information at the starting point of food supply chain, farmhouses, and next stages of food supply chain. This way manufacturer and processor of food can easily be tracked animals meat and milk, came from farmlands. Manufacturer of meat industry uses two types of cold chain management in delivering packed meat to consumers i.e. frozen storage and cold storages. These storage stages have sensors that sends periodic values to Blockchain. Temperature is key factor of post-processing stage at the food processing because high temperature make the food contaminated. So temperature and humidity checks, monitored and make the transaction during transaction from food manufacturer to next stages of supply chain network. IoT devices helps to scan temperature and humidity level at the every stage of supply chain network i.e. producer, processor, logistics, distributor, retailer and customer. First scan point is the stage of butchery when animals move to slaughterhouse where health inspection and segmentation of food is done. Then asset is transported to food processor and its transaction is recorded on Blockchain. During transportation, temperature and humidity sensor sends the data over blockchain after some time. These transactions contains every important information of asset. Tracking among stages is being done by IDs of every supply chain actor. Food processor is responsible of packing, storage and process the food items. From food processors packed and processed food items are transferred to warehouses to store. Retailers buy the bulk of food cartons from distributors and sale them to consumers. Consumers can able to read all entered information and history of food products up to the first participant of supply chain network.

4.2.1 Proposed Solution

4.2.1.1 Meat Supply Chain Network

In case of meat and milk supply chain, following two type of cases can be made i.e. RFID tag affix on every animal and transaction will make for every animal. Second case is lot of animals transfer to butchery and only one transaction is made for one lot. Similar cases is also considered for milk. 4.4 is the proposed model for case one where asset is created on the blockchain at first and every RFID tag is affixed on every animal. Transaction TRANSFER_TO_SLAUGHTERHOUSE is made when animal is transferred to butchery and this transaction gave all information about asset and butcher. These transactions present the state transitions of assets as how animal transform into carcass and then changed into processing food. 4.1 presents all transactions details, IoT scan points and at what stage any transaction will send to the Blockchain.

Second case is for lots of animals in which number of animals send to butchery, from where carcass send to food processor. A lot of animals have same lot ID on the food packets that get from hash of animal IDs. This way consumer can trace back to lots from which his product processed from. During transportation, IoT devices make the transaction of current temperature and humidity periodically. 4.5 presents proposed solution for this case and detailed transactions describes in 4.2.

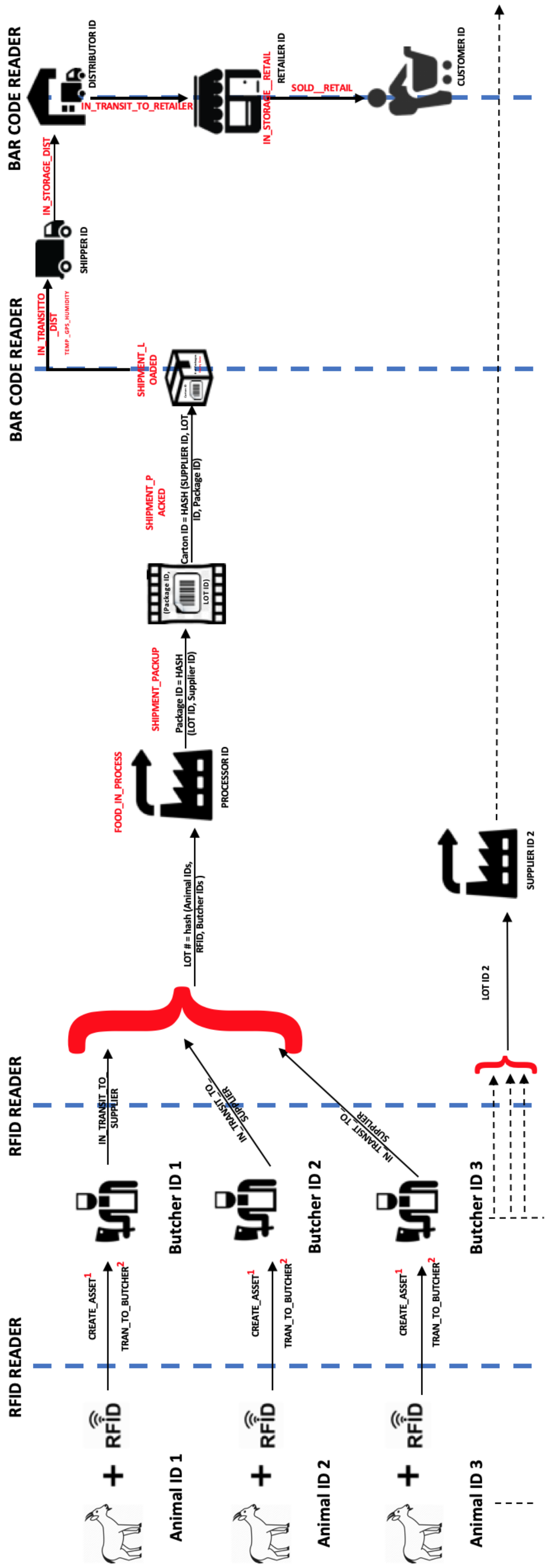

Figure 4.4: Proposed Solution of Meat Case I

Scan Check-points	Blockchain Transactions	Traceability Information
TRANFER TO SLAUGHTER-HOUSE	TRAN_TO_BUTCHER	Animal ID, BREED, Last Vaccination Date, Butcher ID -> New OWNER
TRANFER TO SUP-PLIERFOOD PROCESSOR	IN_TRANSIT_TO_SUPPLIER	LOT No., Butcher ID, Supplier ID
FOOD IN PRO-CESSING	FOOD_IN_PROCESS	LOT No., Temperature, Meat Grade, Regulator ID
FOOD PACKUP	SHIPMENT_PACKUP	Packed Date & Time, Expiry date, weight, type of meat, Optimum Temperature, Total Pieces in Package, Package ID
PACKED FOOD	SHIPMENT_PACKED	Packed Date & Time, Expiry date, weight, type of meat, Optimum Temperature, Total Packages in Carton, Carton ID
SHIPMENT LOADED	SHIPMENT_LOADED	Shipment ID, Total No. of Cartons, Optimum Temperature, From: Shipper ID, To: Distributor ID, Estimated Duration
TRANSFER TO DISTRIBU-TOR	IN_TRANSIT_TO_DIST, TEMP_GPS_HUMIDITY	Weight, Temperature, Relative Humidity, Mode of Transport, Current Location
STORE IN WAREHOUSE	IN_STORAGE_TO_DIST	Storage Location, Humidity, Temperature, Operator ID, Storage Date & Time
TRANSFER TO RETAILER	IN_TRANSIT_TO_RETAILER	Weight, Temperature, Relative Humidity, Mode of Transport, Current Location
STORE IN RE-TAIL STORE	IN_STORAGE_TO_RETAIL	Storage Location, Humidity, Temperature, Operator ID, Storage Date & Time
SOLD TO CUS-TOMER	SOLD_RETAIL	RETAIL ID, Customer ID, Purchase Date & Time, Price, Weight, Cashier ID

Table 4.1: TRANSACTIONS IN BLOCKCHAIN BASED MEAT SUPPLY CHAIN NETWORK

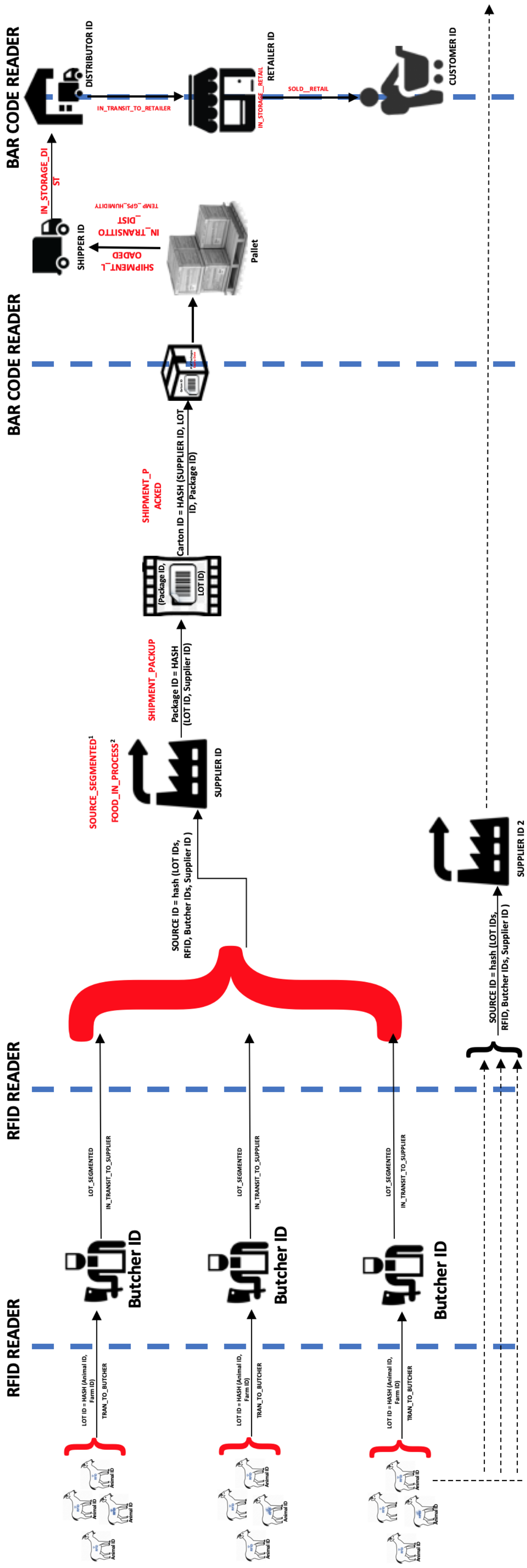

Figure 4.5: Proposed Solution – Lot Case of Meat

Scan Check-points	**Blockchain Transactions**	**Traceability Information**
CREATE AS-SET – put RFID tag to Animal	CREATE_ASSET	Animal ID, BREED, Last Vaccination Date, Farm ID
TRANSFER TO SLAUGH-TERHOUSE	TRANS_TO_BUTCHER	LOT IDs, No. of Animals in Lot, Purchase Date & Time, Farm ID, Type of Animals, Butcher ID -> New OWNER
TRANFER TO SUPPLI-ER/FOOD PROCESSOR	IN_TRANSIT_TO_SUPPLIER	Source ID, Butcher ID, Supplier ID, Transfer, Date & Time, Total Meat in Kg
SOURCE SEG-MENTED	SOURCE_SEGMENTED	The transition from animal carcass to sliced meat & separate different parts to supply and process. (track source ID)
FOOD IN PRO-CESSING	FOOD_IN_PROCESS	Source IDs, Temperature, Meat Grade, Regulator ID
FOOD PACKUP	SHIPMENT_PACKUP	Packed Date & Time, Expiry date, weight, type of meat, Optimum Temperature, Total Pieces in Package, Package ID
SHIPMENT LOADED	SHIPMENT_LOADED	Shipment ID, Total No. of Cartons, Optimum Temperature, From: Shipper ID, To: Distributor ID, Estimated Duration
TRANSFER TO DISTRIBU-TOR	IN_TRANSIT_TO_DIST TEMP_GPS_HUMIDITY	Weight, Temperature, Relative Humidity, Mode of Transport, Current Location
STORE IN WAREHOUSE	IN_STORAGE_TO_DIST	Storage Location, Humidity, Temperature, Operator ID, Storage Date & Time
TRANSFER TO RETAILER	IN_TRANSIT_TO_RETAILER	Weight, Temperature, Relative Humidity, Mode of Transport, Current Location
STORE IN RE-TAIL STORE	IN_STORAGE_TO_RETAIL	Storage Location, Humidity, Temperature, Operator ID, Storage Date & Time
SOLD TO CUS-TOMER	SOLD_RETAIL	RETAIL ID, Customer ID, Purchase Date & Time, Price, Weight, Cashier ID

Table 4.2: DETAILED TRANSACTIONS IN LOT MEAT CASE

4.2.1.2 Milk Supply Chain Network

For milk supply chain network, this thesis considers only the use case of supplying the raw milk to end customer. First use case is where milk of every animal is treated as batch and records temperature of milk storage. Milk transferred to food processor in buckets that contains unique bar code and temperature of milk is recorded by using temperature sensor, records on blockchain. Food processor processes the milk, packed in packet and make different products from cheese. Every packed product contains lot ID, container ID along with product ID. This all information updated on blockchain at the stage of processing along with processor ID, bought Date and time, dairy farm ID, processing temperature. 4.6 presents how blockchain based milk supply chain transfer the ownership of asset and which transactions need to flow the information to ensure the traceability. 4.3 catalogues all the required transactions in milk supply chain network. Other use-case considers Pakistan's small businesses, in which dairy farm supplies raw milk, collectors collect the milk and delivers to consumers. In this case, milk collects in containers lot by lot and transported it customers. 4.5 depicts the flow of information and 4.4different transactions of this model.

4.2.2 Model Evaluation and Discussion

Traditional food tracking systems discussed in chapter 3 that can be compared with blockchain based food traceability system. Comparison based on following parameters such as: efficiency, cost of implementation and operation, latency, waste management, traceability and tracking feature. By using

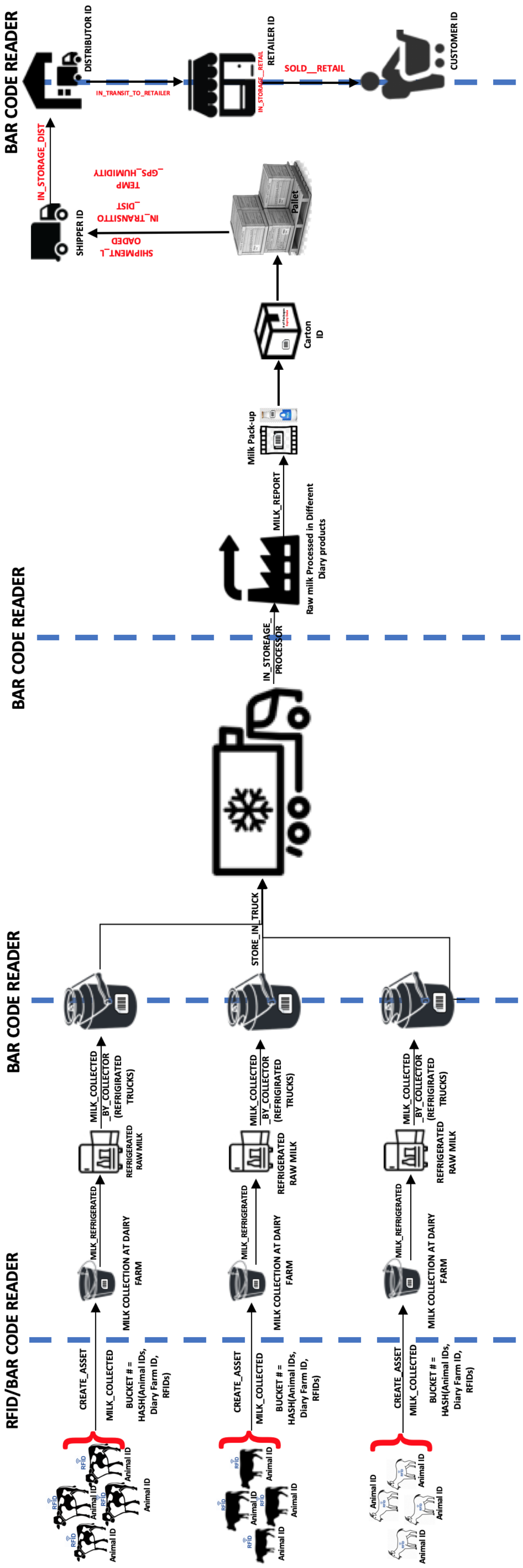

Figure 4.6: Blockchain based Milk Supply Chain Network

Scan Checkpoints	**Blockchain Transactions**	**Traceability Information**
CREATE ASSET – put RFID tag to Animal	CREATE_ASSET	Animal ID, BREED, Last Vaccination Date, Dairy Farm ID, Feed, Yield (milk per day in Kg)
MILKING AT DAIRY FARM	MILK_COLLECTED	Animal IDs, Date & Time, Total Amount of Milk Kg, Bucket ID = HASH (All IDs)
STORE IN REFRIGERATED	MILK_REFRIGERATED	Transaction must contain Bucket ID and temperature at which it's store until collector is not collected
RAW MILK COLLECTION BY REFRIGERATED TRUCKS	STORE_IN_TRUCK	Truck ID, Container ID, Temperature
TRANSFER TO DAIRY PROCESSOR	IN_TRANSIT_TO_PROCESSOR	Milk from: , Optimum Temperature, Total MILK in Kg, Truck ID
STORE IN PROCESSOR, MILK REPORT	IN_STORAGE_PROCESSOR, MILK_REPORT	Checks regulatory parameters of milk, Processing Temperature, Regulator ID, Processor ID
MILK PACKUP	MILK_PACKUP	Product ID, Processor ID, Optimum Temperature, Quantity, Price
SHIPMENT LOADED	SHIPMENT_LOADED, TEMP_GPS_HUMIDITY	Weight, Temperature, Relative Humidity, Mode of Transport, Current Location, Truck ID, From: Processor ID, To: Distributor ID
STORE IN WAREHOUSE	IN_STORAGE_TO_DIST	Storage Location, Humidity, Temperature, Operator ID, Storage Date & Time
TRANSFER TO RETAILER	IN_TRANSIT_TO_RETAILER	Weight, Temperature, Relative Humidity, Mode of Transport, Current Location
STORE IN RETAIL STORE	IN_STORAGE_TO_RETAIL	Storage Location, Humidity, Temperature, Operator ID, Storage Date & Time
SOLD TO CUSTOMER	SOLD_RETAIL	RETAIL ID, Customer ID, Purchase Date & Time, Price, Weight, Cashier ID

Table 4.3: DETAILED TRANSACTIONS OF BLOCKCHAIN BASED MILK SUPPLY CHAIN NETWORK – CASE I

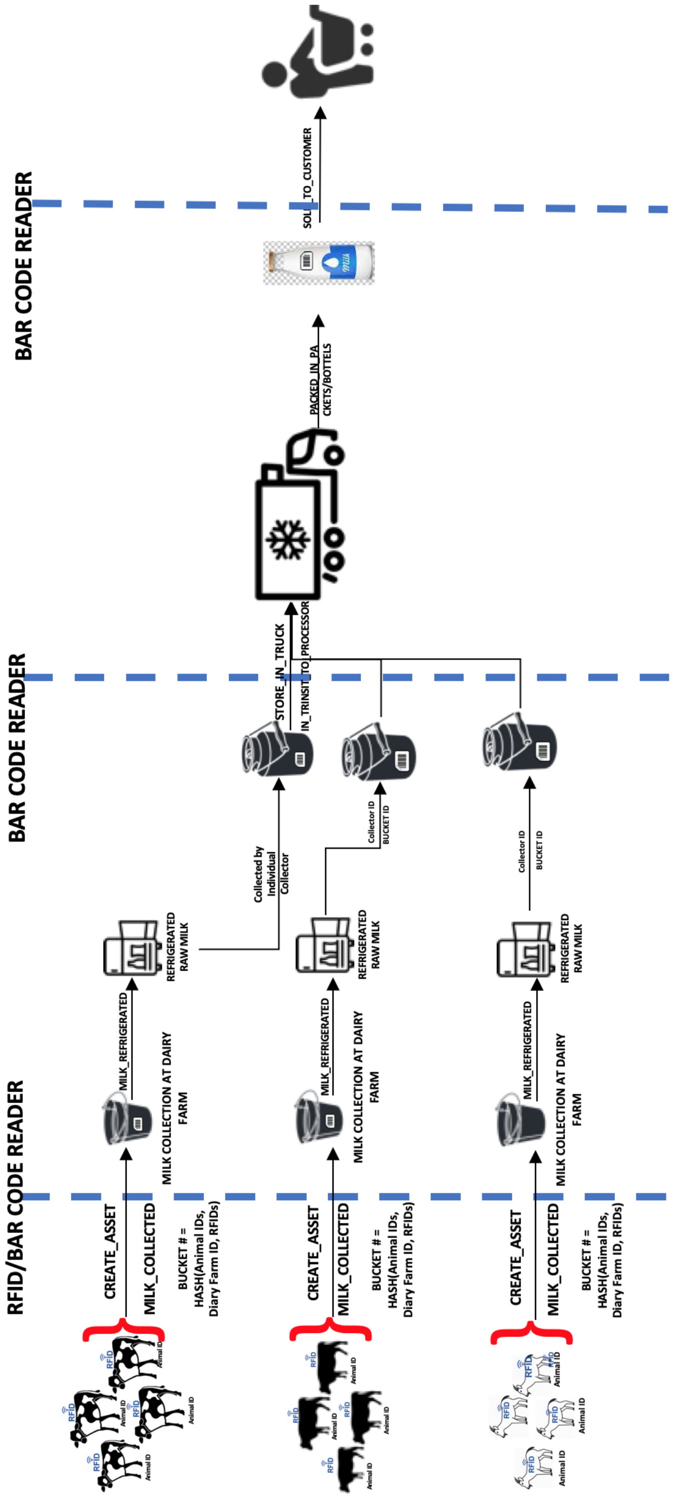

Figure 4.7: Blockchain Model for Small Milk Ventures

Scan Checkpoints	**Blockchain Transactions**	**Traceability Information**
CREATE ASSET – put RFID tag to Animal	CREATE_ASSET	Animal ID, BREED, Last Vaccination Date, Dairy Farm ID, Feed, Yield (milk per day in Kg)
MILKING AT DAIRY FARM	MILK_COLLECTED	Animal IDs, Date & Time, Total Amount of Milk Kg, Bucket ID = HASH (Animal IDs, Diary Farm ID, RFIDs)
STORE IN REFRIGERATED	MILK_REFRIGERATED	Transaction must contain Bucket ID and temperature at which it's store until collector isn't collected.
RAW MILK COLLECTION BY REFRIGERATED TRUCKS	STORE_IN_TRUCK	Truck ID, Container ID, Temperature
COLLECTED RAW PACKED IN BOTTELS/PACKS	PACKED_IN_PACKETS	Product ID, Quantity, Expiry Date & Time
SOLD TO CUSTOMER	SOLD_RETAIL	RETAIL ID, Customer ID, Purchase Date & Time, Price, Weight, Cashier ID

Table 4.4: DETAILED TRANSACTIONS IN MILK SUPPLY CHAIN NETWORK

blockchain based food traceability system, foodborne can easily identified by enquire into chain of transactions of supply chain network about every product. Proposed system provide the functionality to fetch every information about the product by unique Product ID. Fetching product related information is helping IoT layer to record real-time data about the product efficiently and actors of supply chain acts as supervisor that maintains the integrity of actuated data by signed the data digitally. While traditional food tracking systems can provide similar functionality and accuracy but blockchain postulates striking functionality in following ways:

- For horizontally food supply chain, distributed and peer-to-peer architecture save data in multiple copies on every peer, where database silos are used to save the data and maintain the data which is prone to many type of traditional SQL injection attacks, scripting attacks and cross site request forgery.
- Every actor connect their systems to blockchain network and their every action record on the block because of predefined transactions of systems and standard topology of blockchain, but these actions are not so clear on conventional system.
- Every data on the blockchain is visible to other actors of supply chain network and make every action transparent and traceable to corresponding downstream network.
- Blockchain provides the immutability that makes every actor to view every new and past information regarding asset.

- Time efficiency is provided by blockchain to track product in second to address from the consumers because food supply chain spread across continents, where conventional systems would take several days to fetch the data.

- No central authority is owning the data where no supplier have to build an centralized database to manage the products and their activities.

Blockchain enhances the trust among blockchain actors which provides the transparent, fair, uncontrolled system and resolves asymmetry between suppliers and other actors of network. This way consumers can track every information regarding product from where their products flow actor to actor. Tracking make the manufacturers to work honestly as in case of meat supply chains actors concerned about their reputation if they prove to associate with any food outbreak or food borne issues. By this way, blockchain can easily be accountable for any food borne or contaminated issue and ensure the quality within food supply chain network. We can add the regulators in the food supply chain network that can monitor the smart contracts written between different supply chain actors to identified who is responsible if some event occurred or some unethical business practice e.g. food processor set the different prices for different chicken farmers to depreciate the actual price of chicken below the cost of production. Limitations of deploying blockchain based system leading to special training sessions for supply chain actors and portray its importance to determine the adoption rate. But blockchain based systems need special kind of software systems to easily connected with blockchain and update every user action.

Chapter 5

Conclusion and Future Work

5.1 Conclusion

This research contributed to enhance food provenance that is challenge for food supply chain. To create blockchain model for food supply chain is primary objective of this research that minimizes the limitations of conventional food tracking system, enhances the food provenance and give the implementation edge to provide advance food traceability model. This research effort presents that blockchain can be more efficient and robust to improve food provenance, traceability and limit food borne and food contaminated cases while conventional system take weeks to identify as every actor has different system to manage the data and stakeholders don't have every access over data. By proposed system, customer satisfaction increases to certain level and they start trust on supply chain actors that they get product for what they paid.

5.2 Future Work

Future work can be focused on how security is enhance for IoT devices, designing of secure communication with blockchain and lightweight digital signature schemes. There's research gap to fill by identify how rewards can be distributed to provide fair power distribution regarding how blockchain can be used by different entities. It's necessary to identify how the blockchain solutions regarding food provenance can be used at every stage instead of conventional systems, which is only possible if one can only push to network with greater influence. New research can be conducted about how fair power can be distributed between food processors and retailers as these two entities spread across continents and have complex sub-system. Other aspect is scalability of blockchain model for food supply chain. It's important for the scenario if one food processor supplies food items to multiple retailers. So this system needs private channels for every retailer because every communication aspect needs privacy from other parties.

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Appendices

Appendix

Model File

```
namespace org.example.trading
asset Commodity identified by tradingSymbol {
    o String tradingSymbol
    o String description
    o String mainExchange
    o Double quantity
    --> Trader owner}
participant SCMember identified by SCMId {
    o String SCMId
    o String firstName
    o String lastName
    o String OrgName optional}

participant Supplier extends supplyChainMember {}

participant Manufacturer extends supplyChainMember {}

participant Distributor extends supplyChainMember {}

participant Retailer extends supplyChainMember {}

participant Customer extends supplyChainMember {}
transaction Trade {
    --> Commodity commodity
    --> Trader newOwner}
event TradeNotification {
    --> Commodity commodity}
transaction FetchCommodities {}
```

```
event sixtyNotification {
    --> Commodity commodity}
```

Logic File

```
/**
 * Track the trade of a commodity from one trader
 to another
 * @param {org.example.trading.Trade} trade -
 the trade to be processed
 * @transaction
 */
async function tradeCommodity(trade) {
// eslint-disable-line no-unused-vars
    trade.commodity.owner = trade.newOwner;
    const assetRegistry = await getAssetRegistry
    ('org.example.trading.Commodity');
    const tradeNotification = getFactory().newEvent
    ('org.example.trading', 'TradeNotification');
    tradeNotification.commodity = trade.commodity;
    emit(tradeNotification);
    await assetRegistry.update(trade.commodity);}
/**
 * Remove all high volume commodities
 * @param {org.example.trading.FetchCommodities}
 remove - the remove to be processed
 * @transaction
 */
async function FetchCommodities(get) {
// eslint-disable-line no-unused-vars
    const assetRegistry = await getAssetRegistry
    ('org.example.trading
    .Commodity');
    const results = await query
    ('selectCommoditiesWithHighQuantity');
    results.forEach(async trade => {
        const sixtyNotification = getFactory().
        newEvent ('org.example.trading',
        'SixtyNotification');
        sixtyNotification.commodity = trade;
        emit(sixtyNotification);
```

```
        await assetRegistry.get(trade);  });
     let count = results.length;
     console.log(count);}
async function isAnyAssetBeingShipped(assets){
    try{
        for(var i = 0; i< assets.length; i++){
            console.log("Asset... " + assets[i].owner);     }
    }catch(e){
        throw 'Asset with ID ' + assets[i].getIdentifier() +
        ' does not exist';    }
    for(var i = 0; i < assets.length;i++){
        var assetIdentifier = 'resource:
        org.logistics.testnet
        .Commodity#' +  assets[i].GTIN;
        console.log(assetIdentifier);
        const shipment = await query(
        'getShipmentWhereCommodityExists',
        {commodities:assetIdentifier});
        console.log("Asset: " + assetIdentifier);
        console.log(shipment);
        console.log("Shipment size: " + shipment.length);
        if (shipment.length == 0){
            return false;
        }else{
            return true;   } }}
async function supplyMemberExists(supplyChainMember){
    if(supplyChainMember === undefined){
        return false;   }
    var memberID = supplyChainMember.getIdentifier();
    var memberType = supplyChainMember.getType();
    if(memberID === undefined || memberID == '' ||
    memberID === null ){
        return false;
    }else{
        return getParticipantRegistry('
        org.logistics.testnet.'  + memberType)
        .then(function (participantRegistry) {
        return participantRegistry.exists(memberID);
        })
        .then(function (exists) {
        return exists;
        })
        .catch(function (error) {
```

```
        }); }}
/**
 *
 * @param {org.logistics.testnet.CreateShipmentAndContract}
 shipmentAndContract - the CreateShipmentAndContract transaction
 * @transaction
 */
async function CreateShipmentAndContract
(shipmentAndContract){
    //TODO: CHECK PERMISSIONS
    return supplyMemberExists(shipmentAndContract
    .owner).then (function(exists){
        console.log("Exists? " + exists);
        if (!exists)
            throw 'Shipment owner does not exist.'
        else
            return supplyMemberExists(shipmentAndContract
            .buyer);}).then(function(exist){
        console.log("Exists? " + exists);
        if (!exists)
            throw 'Shipment buyer does not exist.'
    }).then(function(exists){
        var assetExchanged = shipmentAndContract.assetExchanged;
        for (var i = 0; i < assetExchanged.length; i++) {
            if (assetExchanged[i].owner.gs1CompanyPrefix != shipmentAndContract.owner.
                throw 'The shipment owner is not the owner of all
                the commodities in the shipment (check if all the
                commodities exist).';     } }
        var now = new Date();
        if (shipmentAndContract.arrivalDateTime <= now) {
            throw 'Arrival Date is set to before the current date.';
        }
        console.log("before creating");
        CreateShipmentAndContractAuxiliar
        (shipmentAndContract);
        return getAssetRegistry('org.logistics.
        testnet.ShipmentBatch')
    }).then(function(shipmentAssetRegistry){
        //console.log("Finally... " + shipmentAssetRegistry);
        return getAssetRegistry('org.logistics.
        testnet.OrderContract');   });}
/**
 *
```

```
 * @param {org.logistics.testnet.UpdateShipment} updatedItems -
 the UpdateShipment transaction
 * @transaction
 */
async function UpdateShipment(transactionItems) {
    //TODO: CHECK PERMISSIONS
    var newHolder;
    var newStatus = transactionItems.status;
    var newLocation = transactionItems.newLocation;
    var shipment = transactionItems.shipment;
    var oldLocation = shipment.location;
    if(transactionItems.newHolder != '' &&
    transactionItems.newHolder != null)
         newHolder = transactionItems.newHolder;
    else
        newHolder = shipment.holder;
    const holderExists = await supplyMemberExists(newHolder);
    if(!holderExists)
        throw 'The specified holder does not exist.'
    console.log("Holder exists: " + holderExists);
    if(newStatus == 'DELIVERED'){
        if(newHolder.id == shipment.contract.buyer.id){
            if(shipment.contract.payOnArrival){
                if(validPayment(shipment, transactionItems)){
                    payOut(shipment.contract.buyer,
                    shipment.contract.seller, shipment);
                    shipment.status = newStatus;
                    shipment.location = newLocation;
                }else{
                    throw 'Not enough money to make the payment
                    transaction on delivery';      }
            }else{
            }
                shipment.status = newStatus;
                shipment.location = newLocation;
                shipment.owner = newHolder;
                shipment.holder = newHolder;
                //change owner of all assets individually
                for(var i=0; i<shipment.assetExchanged.
                length; i++){
                shipment.assetExchanged[i].owner = newHolder;
                }   }else{
            throw 'Not delivering to the contract buyer!'; }
```

```
    }else{
        shipment.status = newStatus;
        shipment.location = newLocation;
        shipment.holder = newHolder; }
    //checkLocationFraud(newLocation, shipment.contract.expectedArrivalLocation,shipme
    const commodityAssetRegistry=await getAssetRegistry('org.logistics.testnet.Commodi
    await commodityAssetRegistry.updateAll(
    shipment.assetExchanged);
    const shipmentAssetRegistry = await getAssetRegistry(
    'org.logistics.testnet.ShipmentBatch');
    await shipmentAssetRegistry.update(shipment);
    let event = getFactory().newEvent('org.
    logistics.testnet', 'ShipmentUpdate');
        event.shipment = shipment;
        emit(event);}
/**
 *
 * @param {org.logistics.testnet.UpdateCommodity} update -
 the UpdateCommodity transaction
 * @transaction
 */
async function UpdateCommodity(update) {
    commodity = update.commodityToUpdate;
    commodity.type = update.type;
    commodity.name = update.name;
    commodity.description = update.description;
    commodity.itemCondition = update.itemCondition;
    const commodityAssetRegistry=await getAssetRegistry('org.logistics.testnet.Commodi
    await commodityAssetRegistry.update(commodity);}
/**
 *
 * @param {org.logistics.testnet.DeleteCommodity} data -
 the DeleteCommodity transaction
 * @transaction
 */
async function DeleteCommodity(data) {
    commodity = data.commodityToDelete;
    const beingShipped = await isAnyAssetBeingShipped
    ([commodity]);
    if (beingShipped)
        throw 'Can not transform products: 1 or more
        products are currently part of a shipment batch.';
    const commodityAssetRegistry=await getAssetRegistry
```

```
    ('org.logistics.testnet.Commodity');
    await commodityAssetRegistry.remove(commodity);}
/**
 *
 * @param {org.logistics.testnet.ReportDamagedGood}
 damageReport - the ReportDamagedGood transaction
 * @transaction
 */
async function ReportDamagedGood(damageReport) {
    var damagedGood = damageReport.damagedGood;
    const commodityAssetRegistry = await getAssetRegistry
    ('org.logistics.testnet.Commodity');
    await commodityAssetRegistry.update(damagedGood);}
/**
 *
 * @param {org.logistics.testnet.TransformCommodities}
 transformation - the TransformCommodity transaction
 * @transaction
 */
async function TransformCommodities(transformation) {
    console.log()
    var inputProducts = transformation.commoditiesToBeConsumed;
    var outputProducts = transformation.commoditiesToBeCreated;
    var createdCommodities = [];
    const beingShipped = await isAnyAssetBeingShipped
    (inputProducts);
    console.log("Being shipped: " + beingShipped);
    if (beingShipped)
        throw 'Can not transform products: 1 or more products
        are currently part of a shipment batch.';
    for(var i = 0; i<outputProducts.length; i++){
        const ownerExists = await supplyMemberExists
        (outputProducts[i].owner);
        if(!ownerExists)
        throw 'Can not transform products.Unexistant owner
        of the output Commodity ' + outputProducts[i].
            getIdentifier();
    }
    if (inputProducts.length <= 0 || outputProducts.length <= 0){
        throw 'The number of commodities consumed or created
        can not be 0. To create or delete commodities, use the
        corresponding Add or Delete transactions.'
    }
```

```
    const commodityAssetRegistry = await getAssetRegistry
    ('org.logistics.testnet.Commodity');
    var factory = getFactory();
    for (var i = 0; i < outputProducts.length; i++){
      createdCommodities[i] = factory.newResource(
      'org.logistics.testnet', 'Commodity',
      outputProducts[i].GTIN);
      createdCommodities[i].owner = outputProducts[i].owner;
      createdCommodities[i].type = outputProducts[i].type;
      createdCommodities[i].GTIN = outputProducts[i].GTIN;
      createdCommodities[i].name = outputProducts[i].name;
      createdCommodities[i].description = outputProducts[i]
      .description;
      createdCommodities[i].itemCondition = outputProducts[i]
      .itemCondition;
    }
    let event = getFactory().
    newEvent('org.logistics.testnet',
    'CommodityTransformation');
        event.oldCommodities = inputProducts;
        event.newCommodities = createdCommodities;
        emit(event);
}
/**
 *
 * @param {org.logistics.testnet.RevertTransformation}
 transformation - the RevertTransformation transaction
 * @transaction
 *
async function RevertTransformation(transformation) {
    var inputProducts = transformation.input;
    var outputProducts = transformation.output;
    const commodityAssetRegistry = await getAssetRegistry
    ('org.logistics.testnet.Commodity');
    var factory = getFactory();
}
*/
/**
 *
 * @param {org.logistics.testnet.TransferCommodityPossession}
 transfer -
 the TransferCommodityPossession transaction
 * @transaction
```

```
 */
async function TransferCommodityPossession(transfer) {
    try {
        var newOwner = transfer.newOwner;
        var oldOwner = transfer.commodity.owner;
        var commodity = transfer.commodity;
        const isBeingShipped = await isAnyAssetBeingShipped
        ([commodity]);
        if (isBeingShipped)
            throw 'Can not transfer possession: the product is currently
            part of a shipment batch.';
        var currentShipments = await getAssetRegistry('org.logistics
        .testnet.ShipmentBatch');
        const ownerExists = await supplyMemberExists(newOwner);
        if (!ownerExists)
            throw 'The specified participant does not exist!';
        transfer.commodity.owner = transfer.newOwner;
        const commodityAssetRegistry = await getAssetRegistry('org.logistics
        .testnet.Commodity');
        await commodityAssetRegistry.update(commodity);
        let event = getFactory().newEvent
        ('org.logistics.testnet', 'changeOwnershipEvent');
        event.commodity = commodity;
        event.oldOwner = oldOwner;
        event.newOwner = newOwner;
        emit(event);
    } catch (error) {
        console.log(error);
        throw error; }}
/**
 * A temperature reading has been received for a shipment
 * @param {org.logistics.testnet.TemperatureReading}
 temperatureReading - the TemperatureReading transaction
 * @transaction
 */
async function temperatureReading(temperatureReading) {
    const shipment = temperatureReading.shipment;
   console.log('Adding temperature ' + temperatureReading
   .centigrade +' to shipment '+ shipment._$identifier);
    if (shipment.temperatureReadings) {
        shipment.temperatureReadings.push
        (temperatureReading);
```

```
    } else {
        shipment.temperatureReadings = [temperatureReading];  }
    // add the temp reading to the shipment
    const shipmentRegistry = await getAssetRegistry('
    org.logistics.testnet.ShipmentBatch');
    await shipmentRegistry.update(shipment);}
```

Access Control List

```
/**
 * Access control rules for mynetwork
 */
rule Default {
    description: "Allow all participants
    access to all resources"
    participant: "ANY"
    operation: ALL
    resource: "org.example.trading.*"
    action: ALLOW}
rule SystemACL {
    description:  "System ACL to permit all access"
    participant: "org.hyperledger.composer.
    system.Participant"
    operation: ALL
    resource: "org.hyperledger.composer.system.**"
    action: ALLOW}
rule NetworkAdminUser {
    description: "Grant business network administrators full
    access to user resources"
    participant: "org.hyperledger.composer.
    system.NetworkAdmin"
    operation: ALL
    resource: "**"
    action: ALLOW}
rule NetworkAdminSystem {
    description: "Grant business network administrators
    full access to system resources"
    participant: "org.hyperledger.composer.
    system.NetworkAdmin"
    operation: ALL
    resource: "org.hyperledger.composer.system.**"
```

```
  action: ALLOW}
```

Query File

```
query selectCommodities {
  description: "Select all commodities"
  statement:
      SELECT org.example.trading.Commodity}
query selectCommoditiesByExchange {
  description: "Select all commodities based on their
  main exchange"
  statement:
      SELECT org.example.trading.Commodity
          WHERE (mainExchange==_$exchange)}
query selectCommoditiesByOwner {
  description: "Select all commodities based on their owner"
  statement:
      SELECT org.example.trading.Commodity
          WHERE (owner == _$owner)}
query selectCommoditiesWithHighQuantity {
  description: "Select commodities based on quantity"
  statement:
      SELECT org.example.trading.Commodity
          WHERE (quantity >= 60)}
query getHistorianRecords {
  description: "All transactions recorded"
  statement: SELECT org.hyperledger.composer.
  system.HistorianRecord}
//  all transactions submitted by person X
query getHistorianByPerson {
  description: "Get all historian records by participant"
  statement: SELECT org.hyperledger.composer.
  system.HistorianRecord
  WHERE (transactionType == _$participantInvoking)}
// ALl transactions of type X;
query getHistorianByType {
  description: "Get all Historian records by type"
  statement: SELECT org.hyperledger.composer.
  system.HistorianRecord
  WHERE (transactionType == _$type)}
//Get damaged goods transactions
```

```
query getDamagedGoodsTransaction {
  description: "Get all transactions associated with
  damaged goods"
  statement:
  SELECT org.logistics.testnet.ReportDamagedGood
  WHERE (damagedGood == _$damagedGood)}
//Get damaged goods transactions
query getCreatedShipmentsTransactions {
  description: "Get all transactions associated with
  damaged goods"
  statement:
  SELECT org.logistics.testnet.CreateShipmentAndContract}
//Get damaged goods transactions
query getCommoditiesTransformations {
  description: "Get all transactions associated with
  damaged goods"
  statement:
  SELECT org.logistics.testnet.TransformCommodities}
query getCommodityOwner {
  description: "Get the owner of a commodity"
  statement:
      SELECT org.logistics.testnet.Commodity
          WHERE (owner == _$owner)}
query getShipmentWhereCommodityExists{
  description: "Get the shipment where a certain
  commodity is included"
  statement:
      SELECT org.logistics.testnet.ShipmentBatch
          WHERE (assetExchanged CONTAINS _$commodities)}
```