THE REPUBLIC OF TURKEY
BAHCESEHIR UNIVERSITY

A CONCEPTUAL BLOCKCHAIN MODEL DEVELOPMENT FOR FOOD SUPPLY CHAIN TRACEABILITY OF CHEESE MANUFACTURING

Master Thesis

ELİF DURSUN

ISTANBUL, 2021

THE REPUBLIC OF TURKEY
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GRADUATE SCHOOL
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ABSTRACT

A CONCEPTUAL BLOCKCHAIN MODEL DEVELOPMENT FOR FOOD SUPPLY CHAIN TRACEABILITY OF CHEESE MANUFACTURING

Elif DURSUN

Master of Business Administration

Thesis Supervisor: Prof. Dr. Yavuz GÜNALAY

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This study aims to propose an alternative traceability framework for food supply chains. Blockchain technology is a milestone for many of the business practices. Its value is increasing as it offers new ways of doing business. It is being adopted in various sectors such as pharmacy, shipping, automotive, and food especially. Immutable and secured structure of the technology is a lot promising for the supply chains in urgent need of reliable and traceable chains. Trustless network based on consensus is also important for the multi-staked structure of food supply chains. Food is essential to sustainable health conditions. Therefore, tracking and controlling the quality of food is important for producers, regulative bodies, and consumers. Consumption of safe food depends on a transparent supply chain where important controls are enabled and performed properly. Information generated on product and processes should be tracked and retrieved easily and transparently.

Although traceability systems exist and applied, we still face food-borne diseases and death from contaminated food. Therefore, developing an alternative food chain traceability solution is at the heart of this thesis. Main objective for pursuing this study is to determine traceability system requirements and develop a conceptual blockchain model as an alternative for the business and consumer benefit. As a result, it is aimed at answering this research question: “Can blockchain technology be used to develop an alternative traceability system for food supply chains?” through an exploratory study methodology. This thesis implies theoretical and practical implications as it deeply analyses traceability systems from a blockchain technology perspective and offers a new conceptual blockchain model to the food supply chain sector. Also, requirements, roles of participants, and transactions for a blockchain traceability system is determined and explained in detail.

Keywords: Traceability System, Blockchain Technology, Food Supply Chain.

ÖZET

PEYNİR ÜRETİMİ TEDARİK ZİNCİRİ İÇİN BLOKZİNCİR TABANLI KAVRAMSAL BİR TAKİP SİSTEMİ MODEL ÖNERİSİ

Elif DURSUN

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Blokzincir teknolojisi iş dünyası için yeni bir kilometre taşıdır ve yeni iş yapma yolları sundukça değer kazanmaktadır. Başta gıda olmak üzere eczacılık, nakliyat, otomotiv gibi çeşitli sektörlerde uygulanmaya başlamıştır. Güvenli ve değiştirilemez yapısıyla tedarik zincirleri için umut vaadeden bir teknolojidir. Tedarik zincirinin çok paydaşlı yapısı için mutabakata dayalı ağ sistemi sunması da diğer bir avantajdır. Sürdürülebilir sağlık koşulları için gıda çok önemlidir. Bu nedenle, gıda kalitesinin izlenmesi ve kontrol edilmesi üreticiler, düzenleyici kurumlar ve tüketiciler için önemlidir. Güvenli gıda tüketimi, önemli kontrollerin etkinleştirildiği ve uygun şekilde gerçekleştirildiği şeffaf bir tedarik zincirine bağlıdır. Ürün ve süreçlerle ilgili üretilen bilgiler kolay ve şeffaf bir şekilde izlenmeli ve ulaşılabilir olmalıdır. Mevcut izlenebilirlik sistemleri hala gıda kaynaklı hastalıklar ve kontamine gıdalardan kaynaklı ölümlere engel olamamaktadır. Bu nedenle, bu çalışma, "Blockchain teknolojisi, gıda tedarik zincirlerinde alternatif bir izlenebilirlik sistemi geliştirmek için kullanılabilir mi?". sorusuna keşifsel metot yöntemi aracılığıyla cevap aramaktadır. Bu tez, izlenebilirlik sistemlerini blokzincir teknolojisi perspektifinden derinlemesine analiz ettiği ve gıda tedarik zinciri sektörüne yeni bir kavramsal blokzincir modeli sunduğu için teori ve pratiğe katkı sağlamaktadır.

Anahtar Kelimeler: Takip Sistemi, Blokzincir Teknolojisi, Gıda Tedarik Zinciri

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ABBREVIATIONS

AI	:	Artificial Intelligence
AML	:	Anti-Money Laundering
B2B	:	Business to Business
B2C	:	Business to Customer
BCT	:	Blockchain Technology
BoL	:	Bill of Lots
BSE	:	Bovine Spongiform Encephalopathy
CAC	:	Codex Alimentarius Commission
CBP	:	Customs and Border Patrol
CD	:	Compact Disc
CTE	:	Critical Tracking Event
dApps	:	Decentralized Applications
DAO	:	Decentralized Autonomous Organizations
DeFi	:	Decentralized Finance
DNA	:	Deoxyribonucleic Acid
EDI	:	Electronic Data Interchange
EFSA	:	European Food Safety Authority
EID	:	Electronic Identification
EPC	:	Electronic Product Code
EQM	:	Enterprise Quality Management
ERP	:	Enterprise Resource Planning
EU	:	European Union
EUROPHYT	:	EU Notification System for Plant Health Interceptions
EXL	:	Extensible Mark-up Language
EY	:	Ernst & Young
FAO	:	Food and Agriculture Organization
FSCM	:	Food Supply Chain Management
GDP	:	Gross Domestic Product
GFL	:	The General Food Law

GIS	:	Geographic Information System
GMO	:	Genetically Modified Organisms
GPS	:	Global Positing System
HACCP	:	Hazard Analysis and Critical Control Points
HTTPS	:	Hyper Text Transfer Protocol Secure
IBM	:	International Business Machines
ID	:	Identity
IFT	:	Institute of Food Technologists
IoT	:	Internet of Things
IP	:	Internet Protocol
ISO	:	International Standards Organization
IT	:	Information Technology
KDE	:	Key Data Element
KYC	:	Know Your Customer
LAO	:	Limited Liability Autonomous Organizations
MD	:	Message Digest
NASA	:	National Aeronautics and Space Administration
NFC	:	Near Field Communication
P2P	:	Peer to Peer
PBFT	:	Practical Byzantine Fault Tolerance
PML	:	Physical Mark-up Language
POP	:	Persistent Organic Pollutant
PoS	:	Proof of Stake
PoW	:	Proof of Work
PPT	:	People, Process, and Technology
QR	:	Quick Response
RASFF	:	Alert System for Food and Feed
RFID	:	Radiofrequency Identification
RS	:	Remote Sensing
SaaS	:	Software as a Service
SCM	:	Supply Chain Management
SCOR Model	:	Supply Chain Operations Reference Model

SFTP	:	Secure File Transfer Protocol
SHA	:	Secure Hash Algorithm
SME	:	Small Medium Enterprise
SMP	:	Skimmed Milk Powder
SQL	:	Structured Query Language
SSH	:	Secure Shell
SSL	:	Secure Socket Layer
TAM	:	Technology Acceptance Model
TLS	:	Transport Layer Security
TRACES	:	Animal Tracing System
TRU	:	Traceable Resource Units
TUIK	:	Türkiye İstatistik Kurumu/Turkish Statistics Institute
UML	:	Unified Modelling Language
UN	:	United Nations
USA	:	United States of America
WebDAVS	:	Web Distributed Authoring and Versioning
WHO	:	World Health Organization
WMP	:	Whole Milk Powder
WSN	:	Wireless Sensor Network
WTO	:	World Trade Organization
XML	:	eXtensible Mark-up Language

1. INTRODUCTION

World population is struggling with food-borne diseases as food supply chains have become more global. Food is the source and fuel of energy and life for humans to sustain existence on this planetary ecosystem. This brings up the question “Are we consuming safe food?” Well, it is a hard question to answer because we are not the suppliers of our own food anymore. Tracking the origin of food, we put on our tables is similar to solving a complex puzzle of thousand pieces. Even it is manufactured in your local area, you cannot be sure that the resources such as seed, pesticide, etc. are 100 percent local. Companies are trying their best to minimize costs and optimize profit. Therefore, they seek for the alternatives of decreasing costs at any stages of supply chain.

Consumers are also a factor in this change. Increasing demand for speed and cheap but high-quality products pushes businesses to alter their way of doing business. Especially in production processes, they try hard to eliminate cost generated through factors of production, inventory, distribution, etc. by utilizing new technologies which offers control over their supply chains.[1] Food sector is one of the major sectors growing rapidly to satisfy the increasing market demand. To manage this demand is not an easy task, especially in today’s complex supply chain structures. Supply chains generate a lot of information and transaction flow between stakeholders from raw material to the end customer and reverse. Managing these flows without any problems is the main objective of every business. Current supply chains lack the ability to provide fully transparent and traceable supply chain structure although the technological developments have been accelerated. Major concerns in supply chains, especially food supply, are reliable product supply, prevent risks and contamination along the supply, access of a common network where real-time information and communication is possible, security and authenticity of information generated on the chain, lack of automated processes regarding information share and use of traditional systems, a proper traceability system where all requirements are satisfied, centralized structure of management risking all information generated, lack

[1] Rodrigues, A., 2020, Modern supply chain management – Optimising global and local supply chains, [Online]

of consumer trust as they don't access to reliable information, and lack of good decision making mechanisms risen from information security problems.

All these concerns lead businesses to seek for alternative solutions to provide customer and other supply chain stakeholders with trustworthy information on the product they consume. New technological developments like artificial intelligence (AI), internet of things (IoT), sensor technologies like near field communication (NFC) and quick response (QR) codes, blockchain technology (BCT), and many more to develop. Among these technologies, blockchain is one of the promising technologies with distributed, decentralized, secure, and consensus-based structure. Although it has gained popularity in financial sector with cryptocurrencies, new application possibilities of technology thanks to its ledger characteristics are on the rise and striking strong in various sectors.
Traceability in supply chain is briefly described as the track and record of a product and all information generated on this product from origin to the consumption forth and back.[2] It is an efficient way to determine anomalies and unexpected events along the chain if managed properly. To do so, businesses develop many tools and ways of tracking the information and product flows of their supply chains. There are various models, software, guidelines to develop a traceability system. However, they all lack standardized structure backed by a strong legislative framework. Blockchain technology is the latest opportunity to solve traceability dilemma in a centralized world. With its characteristics of consensus mechanism, immutable record of data, transparent and accessible network, proof mechanism, automated smart contract structure, and most importantly distributed-decentralized structure, blockchain opens new doors to traceability of food supply chains.

1.1 RESEARCH FOCUS AND METHODOLOGY

Traceability of food supply chain is not only important to companies but also to sustainability of a healthy population. Recent outbreaks are the evidence and an urgent warning to the companies and people to be more aware of what they serve to the public and what they consume. Although traceability systems exist and applied, we still face food-borne diseases and death from contaminated food. Therefore, developing an

[2] Norton, T, 2019, Supply Chain Visibility: Traceability, Transparency, and Mapping Explained, [Online]

alternative food chain traceability solution which could eliminate determined problems through new technologies is at the heart of this thesis. Main objective to pursue this study is to determine traceability system requirements and develop a conceptual blockchain model as an alternative for the business and consumer benefit. As a result, it is aimed at answering this research question “Can blockchain technology be used to develop an alternative traceability system for food supply chains?” in this thesis.

Due to the nature of the topic, this is an exploratory study aiming to develop a conceptual traceability model based on blockchain technology. Model development is backed by secondary research and qualitative analysis of business case reports conducted in supply chain traceability. Also detailed review and analysis of pilot studies from literature are completed. After the analysis of reports and literature, a framework for determining requirements in developing a traceability system is formulated. Following requirement determination, conceptual framework of blockchain model is transcribed. We build the conceptual blockchain traceability framework on a Kashar cheese supply chain system (Please see the reference Figure 3.1).

The structure of this thesis is composed of three main parts divided into sub-sections as:

a. Literature and terminology of blockchain, supply chain, and finally traceability is reviewed and explained in detailed.

b. Requirements of a traceability system is determined at the conceptual components section.

c. Model development and brief traceability scenario is given for the Kashar cheese manufacturing flow.

d. Concluding remarks and limitations are given upon the model development.

e. Future research suggestions are made for those who are interested in new technological adaptations and development of new frameworks.

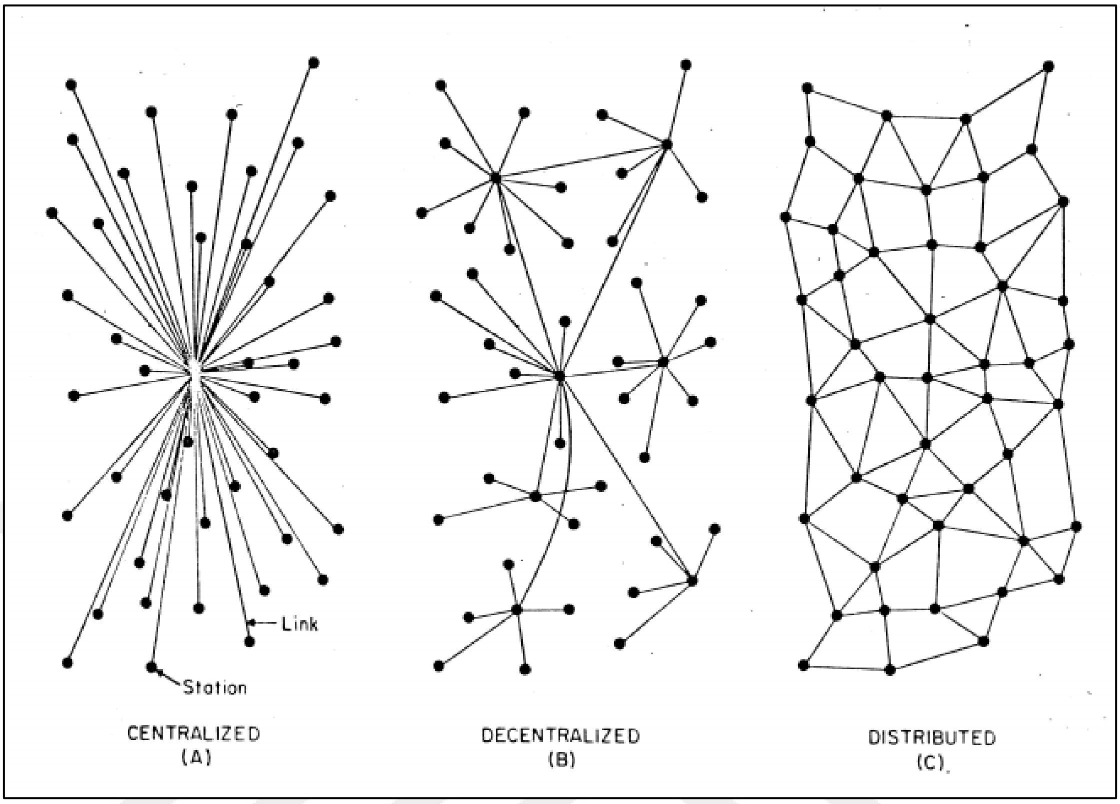
2. LITERATURE REVIEW AND KEY CONCEPTS EXPLAINED

In this section, recent studies on BCT and SC are reviewed. First, we provide a brief definition on blockchain terminology and discuss different BCT systems. Later, importance of supply chain in food industry and current studies on SCM are reviewed. And lastly, existing traceability systems are reviewed from food industry to determine the benefits and challenges on building supply chain traceability systems. This section comprises a basis for the blockchain traceability model we intent to develop in the following section.

2.1 BLOCKCHAIN TECHNOLOGY

As its name indicates, blockchain is a chain of blocks but in a virtual meaning. Blockchain definition with its simplest form made by Gupta (2017, p. 3) as “Blockchain is a shared, distributed ledger that facilitates the process of recording transactions and tracking assets in a business network.” While it used to be a system of arranging data, new technological developments have made blockchain a phenomenon not only in computer science but also in business. Combining the terms of peer-to-peer decentral network, cryptography, distributed database, consensus mechanism, and immutability has enriched the technology in a way that businesses could benefit the most out of it. This evolved technology changed the way strategists see their cost and benefit analysis as well as how they build a business relationship. Another more inclusive than Gupta states that: “Blockchain at its core is a peer-to-peer distributed ledger that is cryptographically secure, append only, immutable (extremely hard to change), and updateable only via consensus or agreement among peers.” (Bashir 2017). Figure 2.1 displays the difference between central, decentral, and distributed networks to better comprehend the idea what blockchain contributed to our lives.

Figure 2.1: Types of networks



Resource: Baran, P., On Distributed Communications Networks, 1964

With blockchain technology, there is a shift towards distributed networks due to the vulnerable structure of centralized networks. Baran (1964, p. 1) explains this problem with his words as "The centralized network is obviously vulnerable as destruction of a single central node destroys communication between the end stations." In distributed systems, where blockchain is based on, this problem is partially solved since all data is distributed among all end stations. Every end station has the copy of confirmed information and it is extremely hard to change this information. Following topics dig into the details of this technology and present examples of application areas.

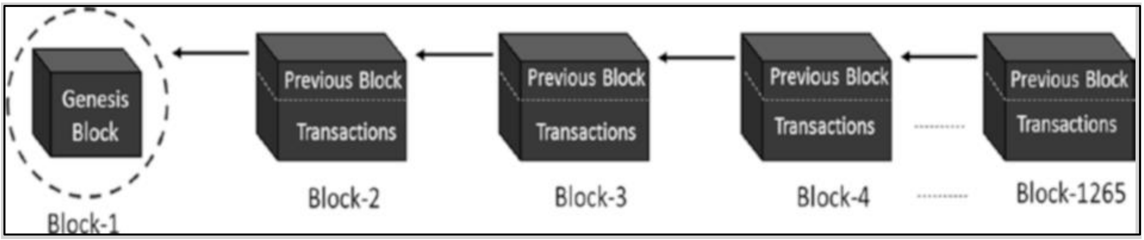
2.1.1 Background and Basics

Blockchain in its infancy was a termed mostly exchanged with Bitcoin since a person or group named Satoshi Nakamoto first mentioned about the technology in his/their paper published for Bitcoin. Dramatic rise of Bitcoin caused blockchain technology to stay in background for a while. Bitcoin is a product of blockchain technology, and other technologies combined, but still a catalyzer for the potential of blockchain to be discovered by business. Bitcoin is a new method of payment backed by different technologies and has been famous among banking and financial sector when it first launched in 2008. However, it is not the first attempt for digital currency system. First examples of electronic cash go back to the 1980s. David Chaum is the person to propose a digital cash and blind signature terms within his paper called "Blind Signatures for Untraceable Payments", and he was the first person founded DigiCash in 1990. First transaction with DigiCash was made in 1994 though. It also utilized from cryptography and other related technologies to Bitcoin (Gates 2017, p. 19). Although a couple of trials are made for an electronic currency after DigiCash, the tempo of developments in this area has remained silent till Nakamoto created or mined genesis block (first block in Bitcoin blockchain network) in 2009 entitled with a message to banks saying, "The Times 03/Jan/2009 Chancellor on brink of second bailout for banks." (Gates 2017).

This was a beginning of a new era for banking and how transactions are made. It was a message for people to see failures and problems of current systems, which have shown itself in 2008 crisis. Bitcoin has rebuilt the trust mechanism between peers as trust to banks and other central institutions was diminishing. It also received attention from users since it provided anonymity, easiness, security, and speed. People do not need intermediaries and don't have to go through all the bureaucracy intermediary institutions require them to accomplish for a transaction.

The first phase for blockchain network was Bitcoin for payment systems, yet it started to evolve as new use areas discovered like smart contracts. There appeared the second phase with Ethereum focusing on smart contracts and decentralized autonomous organizations. They both provide security for blockchain applications and smaller blockchains. The third phase for blockchain is Factom, which is a publication network based on blockchain, providing smaller and more scalable network consisting of federated nodes anchoring itself into Bitcoin and Ethereum blockchain networks (Laurence 2017).

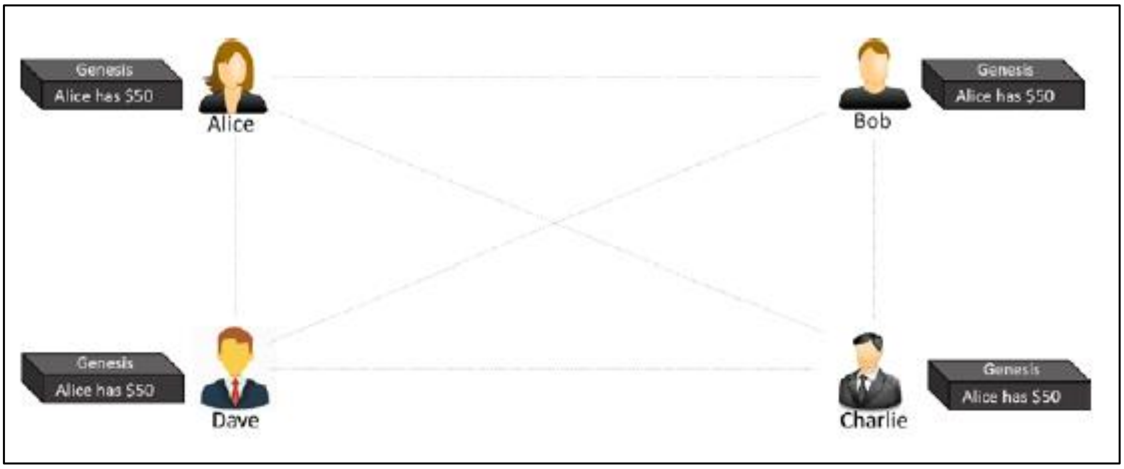
Figure 2.2: Blockchain structure



Resource: Singhal, et. al., Beginning Blockchain: A Beginner's Guide to Building Blockchain Solutions, 2018

Above Figure 2.2 visualizes what a blockchain structure looks like. As the name says, it consists of data blocks starting with the first block called genesis. Blocks enchained with each other after pre-determined rules are performed. Each block contains summarized data of previous block and joins the chain with new data. This process includes hashing and validation from all nodes in the network. To explain it with an example Figure 2.3 and Figure 2.4 visualizes the transaction process performed on a blockchain network. On the Figures, there are four parties – Alice, Bob, Charlie, and Dave - and three of them are exchanging money with each other. They all are named as "node" on the blockchain. In each transaction, a block is formed, and a copy of blocks are saved by all nodes where everyone can trace the history of transaction.

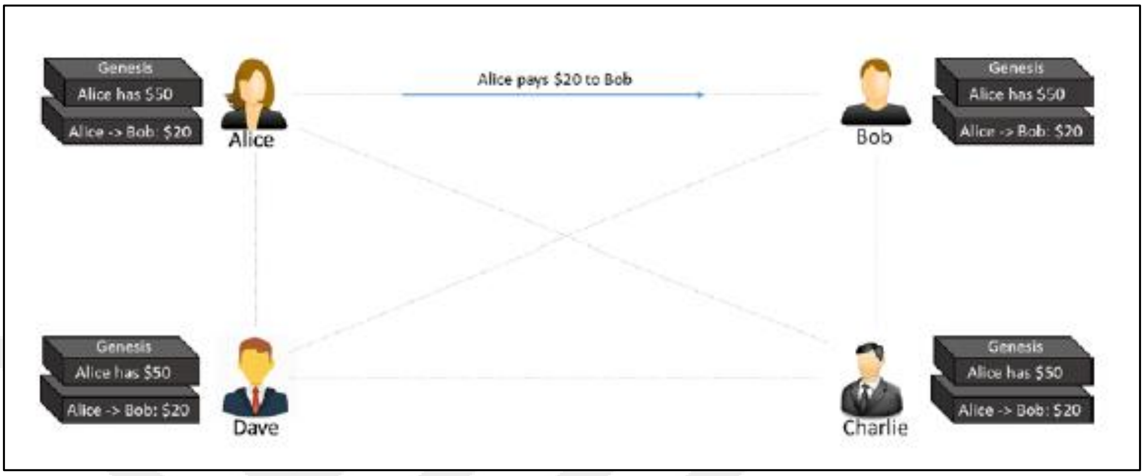
Figure 2.3: The first step of transaction



Resource: Singhal, et. al., Beginning Blockchain: A Beginner's Guide to Building Blockchain Solutions, 2018

Figure 2.3 shows the first step of transaction where Alice has $50. This process is recorded as genesis block on the chain, and all the four nodes have the same copy.

Figure 2.4: The second step of transaction



Resource: Singhal, et. al., Beginning Blockchain: A Beginner's Guide to Building Blockchain Solutions, 2018

In the second step Alice wants to make payment to Bob $20. This transaction is added to the block on the chain as it is displayed on Figure 2.4 and again it is recorded on every node's ledger as an immutable data. All nodes of the chain track and validate the transaction and then save a copy. This process continues like these as new transactions occur. Compared to traditional record keeping methods, blockchain is continuously updated whenever a transaction performed. This feature keeps the system synchronized and prevents fraudulent behavior arising from duplication. Getting rid of mediums for transactions increases the efficiency of network as well as it decreases the amount of time spent during a transaction. Data is verified by all participants or nodes, so validation concerns are eliminated. All in all, blockchain distinguishes itself with its features of consensus-based mechanism, ability of provenance, immutable data structure, and a synchronized ledger (Gupta 2017).

2.1.2 Blockchain Terminology

Developments in the technology have enabled data to be copied and distributed through a network where its limits enlarge across the world. Distributed Ledger Technology, provides everyone on the network to have the same copy of information. However, the old version of this technology did lack security of the data shared within the network. The first development phase towards blockchain technology was the encrypted information sent to network, but encryption alone was not useful for the network since only the owner of data could make sense of it and any change on the data would not be updated on the network. Therefore, it needed to be developed further where there should exist a consensus mechanism provided on the system that includes every participant on the network. With the help of consensus mechanism and encryption, data is recorded in a secure and valid way to the system. The technology accommodating all those features came out as blockchain, in which, it promises to distribute data on the network where everyone has their own encryption, everyone has the same copy of data agreed and validated by the network, and everyone has various permission options to decide with whom they share the data. All technological terminology regarding blockchain is explained within below subtitles (Usta and Doğantekin 2017).

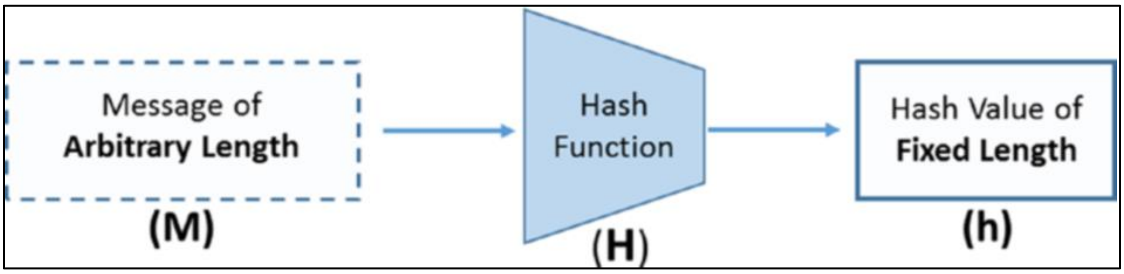
a. Cryptography is the main enabling technology for blockchain, yet it is not a new phenomenon among encryption methods. Julius Caesar was among the first users of encrypted information when they needed secrecy in their communications. The method they used was named as Caesar Cipher which was popular and useful at his time. Now, with the developed technology and variety of languages, it not the most efficient and secure way of sharing information. Depending on its original version, modern cryptography has developed a lot. Information to be share is changed or hashed with letters and numbers so that only the password holder can decrypt it and read the whole information, otherwise the information is kept secured. David Chaum was the first to write a paper where the data can be protected with cryptology and he proposed a method payment based on blind signatures where the data can be hidden before signed and digital signature can be verified without unleashing the hidden data content. Other than Chaum, Szabo focused on solving double spending problem without a central authority is needed, but his work remained as study and not put into life till Satoshi Nakamoto has developed Bitcoin in 2009 (Gates 2017).

Cryptography requires advanced math, and it is the most essential part to build a blockchain system. “It is basically defined as the science of keeping things confidential using encryption techniques.” However, there are other useful features like data integrity, authentication, and non-repudiation that cryptography provides to the world. The basic idea in the cryptography is to encrypt plaintexts with an algorithm and cipher-text. Plaintext does not have to be a text message or information expressed with letters but could be a numerical data or a computer program. Ciphered information is then sent to the receiver who can only decrypt the text with the algorithm and key. As long as the key is kept by the receiver and sender, the message is unreadable by others. There are two types of cryptography – one is symmetric key cryptography, and the other is asymmetric key cryptography. In symmetric key cryptography, the key is the same for processes of encryption and decryption, and it needs a safe communication channel to share this key among sender and receiver. This type is utilized widely for large data sizes via protocols like HTTPS, SFTP, and WebDAVS. In asymmetric key cryptography, on the other hand, requires two keys: public key for encryption and private key for decryption of the message. The message is digitally signed so non-repudiation is provided along with authentication and confidentiality. And also, safe channel requirement for key exchange is removed. (Singhal et al. 2018, p. 34).

b. Peer-to-peer (P2P) Networks are a type of distributed systems that enable blockchain technology and many other applications to process without a central authority. The network is built up by individual computers or nodes that make it possible to exchange data between peers by utilizing each node’s computational power, such as processing power, storage capacity, and bandwidth. Finance sector is the first to experience weakness as cryptocurrencies have been threatened the central authority of banks on money. The main advantage of peer systems is to enable actors on the system get rid of those cost and time expenditure. It is not only at the expense of finance sector but also any business that plays a role of intermediary between groups of people, e.g., buyers and sellers, borrowers and lenders, producers, and consumers, are to be influenced by those peer-to-peer networks (Drescher 2017, pp. 23-24). There are three types of peer-to-peer networks which are classified as pure, hierarchical, and hybrid peer-to-peer networks. Pure networks are based on random connection among nodes where no structured system or network is needed. Exchange of data is done through message forwarding. However, this can cause problem of broadcast storm where too much messaging traffic has to occur. Hierarchical networks, on the other hand, is not free of authority. There are super nodes with higher resource capabilities to manage the communication between peers. This network has disadvantages as well such as it makes the network more vulnerable since a super node is needed for directing exchange of information. Hybrid networks as the last one, is the mix of pure and hierarchical networks as the name states. The network includes nodes and index server in which server enables the connection between nodes through IP addresses. Examples to this network type are Spotify, Napster, and bittorrent. Hybrid systems eliminate the broadcast storm problem but still carries disadvantages of hierarchical systems. Therefore, this network is best fit for small number of inquiries (Li 2017, pp. 9-12).

c. Hash functions and hashing: As being an important enabler to the blockchain technology, hash functions are not a new concept to our world, yet they are unleashed and gained popularity with blockchain. Hashing is an activity under cryptographic primitives which it is related to converting a message or data into a set of letters and numbers. Hashing function, in it is simplest form, a mathematical algorithm that transforms data of any size into a fixed size length of strings that include 32 characters depending on hash type (Laurence 2017, p. 10). Those characters are the representatives of original data expressed in a different form. The path hash functions provide is a one-way direction which cannot be returned to original. Figure 2.5 visualizes the hashing activity in a simplistic way:

Figure 2.5: Hash function in its basic form



Resource: Singhal, et. al., Beginning Blockchain: A Beginner's Guide to Building Blockchain Solutions, 2018

M is the input that needs to be transformed into a hash value or message digest which is represented as h. The mechanism or algorithm to make this transformation happen is hash function denoted as H. The direction is one-way that means output (h) cannot be decrypted backwards. From the hash value, the original input (M) cannot be predicted or found. It is more like fingerprints where it is not possible to determine to whom the fingerprint belongs (Drescher 2017, p. 92). Hash functions are mostly used for digital signatures and data integrity, but also for some protocols, e.g., identification protocols. From digital signature framework, hashing saves time and space since it only requires signing hash value of a long message and verification is done through received signature. From data integrity aspect, hashing helps to determine if the hash value is altered at some point by comparing recomputed hash value and the original hash value. To make those applications happen, it is expected hash functions to have specific properties as follow: (i) Transforming any kind of data to has values as quick as possible, (ii) .Being deterministic meaning where same input data produces the same hash value each time, (iii) Being pseudorandom meaning that the hash value isn't possible to be predicted from the input value, (iv) Being one-way meaning it is not possible to transform hash value to the original input data, and (v) Being collision resistant meaning that hash function does not produce identical hash values for different inputs, being unique to say (Drescher 2017, pp. 72-73). Basically, separated as unkeyed and keyed, there exist different classifications of hash functions: One is MD4 belonging to the message digest (MD) family that is among the oldest one. The other is Secure Hash Algorithm (SHA) family, which is the popular one and varies in versions (ranging from SH-0 to SH-5). It is used in many security tools and

Internet protocols such as SSL, SSH, TSL, etc. Bitcoin utilizes from both families as it uses SHA-256 and RIPEMD-160 – a version of MD – to generate addresses (Singhal et al. 2018, pp. 62-72). Introduced by Ralph Merkle, Merkle tree is a bottom-up tree of hash values to the top value called Merkle root. It works with large amount of data to build a binary tree from bottom (leaf) level which contains raw data to be hashed to the up (root) level. It is used because it helps to verify and protect huge data sets efficiently. (Singhal et al. 2018; Usta and Doğantekin 2017).

d. Consensus mechanisms: Blockchain is a structure with a lot of participants who need to be agree on data that will be added on the system, which should be trusted and valid. Any activity that will be added to the system should be checked and approved by the network, so the integrity is provided. Therefore, blockchain structures need a consensus mechanism that enables data to be processed and validated by the network to be distributed among the peers. In its basic form, consensus is defined as the agreement between nodes of the blockchain network that the data is approved and shared identically on every participant's device (Laurence 2017, p. 12).

   Yet, there still exist questions concerning who will propose the block and how nodes will come to an agreement on the block proposed by any node. In a system every node proposing a block simultaneously, it is inevitable to have a chaotic environment in which tracking and controlling transactions get harder by nature. To prevent such a chaos, consensus mechanisms are helpful for resolving the problem by enforcing specific rules and it requires effort pertaining some cost and reward to take part in a consensus mechanism. This is provided via hash puzzles. Any node willing to propose block should mine the block by solving a complex hash puzzle faster than the others, so the node can gain reward specified by the mechanism.

   An effective consensus mechanism needs to have those three specific aspects: (i) common acceptance of laws, rules, transitions, and states in the blockchain; (ii) common acceptance of nodes, methods and stakeholders that apply these laws and rules; (iii) a sense of identity such that members feel that all members are equal under the consensus laws (Morabito 2017, p. 69). Consensus mechanisms should be designed in a way that any kind of threats and attacks could be eliminated as fast as possible. Basically, what determines the consensus type used in a blockchain is the level of trust and expected threat to the network, but other criteria including decentralized governance, quorum structure (predefined steps), authentication (identity verification), integrity (validation and verification enforcement), privacy (access), and fault tolerance are considered as well (Morabito 2017). Every blockchain requires customized consensus method depending on the nature of entries added on the system.

The most used consensus types are proof of work (PoW), proof of stake (PoS), and Practical Byzantine Fault Tolerance (PBFT) (Singhal et al. 2018; Morabito 2017). P*roof of Work*, as name states, depends on the work of nodes or miners where they need a lot of computational power to solve mathematical puzzles to form a block and add it to the chain. This type of consensus needs a lot of energy, computation, and speed. As more data added to the network, it gets harder to validate and compute which is an increasing challenge for the nodes. Any node trying to propose a block would be avoiding fraudulent behavior, because it is very costly to be rejected by the network. PoW is better for the systems that requires no trust from participants. However, it is very slow, and the speed depends on the last node validates the transaction. Bitcoin and Ethereum blockchains are the most popular examples of PoW consensus but, different transactions require different consensus methods. *Proof of Stake*, on the other hand, is more related to the number of coins owned. The act of validating transactions depends on the possessed stake of coin. Mining is no longer needed because total number of coins on the system are pre-determined, and stakeholders are the ones forging and validating blocks. The more stake of coin hold brings more chance to participate in the block validation. Rewards are also replaced by transaction fees at a cost of bonding specific amount of coin at stake. Becoming a validator on the PoS system is determined by the factors of staking age, randomization, and the wealth of node.[3] Although the largest stake has more chance to be a validator, randomization and coin age selection methods are the most used methods for validation to prevent favoritism. All those characteristics of PoS make

[3] Binance Academy Proof of Stake Explained, 2020. [Online]

the system faster, eco-friendly, cheaper, and secure (Singhal et al. 2018). However, there are critics to this system as well because there is no punishment to those want to behave fraudulently. There are various solution proposals to this problem such as Ethereum's Casper protocol attempts to prevent cheating on the system by having a rule for fraudulent validators to lose their deposits. Peercoin is the first and famous example of PoS system where it is built accordingly with the stake age (The number of days coins held as stake X The number of coins staked).[4] Lastly, *Practical Byzantine Fault Tolerance* as another alternative to the consensus mechanisms takes its name from Byzantine generals' tactics at war to decide if information obtained is true or not. This method is known also as Byzantine general's problem where false information with unwanted results on the network can be shared if majority of participants act maliciously. Therefore, what majority says has importance for validation. At this point, Byzantine Fault Tolerance can be defined as the ability of a network to protect itself from malicious acts with the help of consensus provided by those majority of nodes containing and sharing correct information, so the whole system continues to operate by tolerating Byzantine fault. Basically, system works on synchronizing the servers on the network as other consensus mechanism does, but this does not rely on rewarding or mining. In PBFT, every node on the network has public and private key together and every node know the public keys of others so they can validate the transactions and update their servers. Each node first controls the transaction and then signs and shares it to the network for validation, which is fulfilled by specific number of nodes. Therefore, the network needs to be aware of the status of each node so they can keep any threat away from the network (Singhal et al. 2018; Morabito 2017; Usta and Doğantekin 2017).

2.1.3 Blockchain Types

Just like cloud systems, blockchain has its own dynamics to be available to everyone or not. Every blockchain network is built around different purposes, e.g., actualization of agreements, data storage, money transfer, etc. Therefore, each needs a different structure to fulfill these purposes. The structure chosen defines and determines the features for the

[4] BitcoinWiki, Proof-of-Stake, 2020, [Online]

system to work. Access right is one of the important features to be determined. Questions like "Who can read and write transactions?", "How can transactions be initialized and continued?", and "Who can validate transactions?" are specified by the type of blockchain structure chosen. Some transactions are required to be seen by only a few parties while others are public. There are various approaches for categorizing blockchain types. Drescher (2017, p. 216) summarizes his approach from the perspectives of transparency, privacy, security, and speed. Table 2.1 below is a summary where access rights are distinguished according to these categories.

Table 2.1: Four versions of the blockchain as a result of combining reading and writing

Writing Access	Reading Access and Creation of Transactions	
	Everyone	Restricted
Everyone	Public&Permissionless	Private&Permissionless
Restricted	Public&Permissioned	Private&Permissioned

Resource: Drescher, D., Blockchain Basics: A Non-Technical Introduction in 25 Steps, p. 216

Public blockchains enable everyone to participate on the network as reader, writer, and creator, while private blockchains limit those access rights to a group of participants. On top of these categories, the system is also categorized by permission for writing access. Thus, we can define permissionless blockchain as a system where everyone has the write access to verify, create, and add block to the network, but it varies if it is public permissionless or private permissionless. Private permissionless blockchains limits the reading access and creation as also displayed on the above table. Permissioned blockchain, on the contrary, gives right of writing to a limited group of participants. Again, it is differentiated as public permissioned and private permissioned. In public permissioned blockchain, reading and block creation are only done by those nodes who are given permission by the mechanism while in private permissioned blockchain every action (reading, writing, creating, etc.) is restricted.

In addition to Drescher, Bambara and Allen (2018, pp. 13-14) divide blockchain types into three different categories, where two of them are same as Drescher but the third is a system they call consortium blockchains. In consortium blockchain, system is restricted to only the nodes that are determined on the protocol. An example to this type is a consortium of nine organizations operating as nodes and the block validation is only done by majority participation. Read access as in other blockchain types can optionally be given to the public as well but not necessarily. They call this type of blockchain as "partially decentralized system."

2.1.4 Possible Application Areas of Blockchain

Blockchain Technology roots back to the 1990s. When got popular after 2008, it has first found place in finance sector (Usta and Doğantekin 2017). Yet recently, experts are discovering new areas that blockchain implementation may create a value. Drescher (2017) provides a summary for concrete blockchain application areas which have test applications and might have in the future. Those are listed as, payments, cryptocurrencies, micropayments, digital assets, digital entity, notary services, compliance and audit, tax, voting, and record management. He also states some guiding questions to make a general analysis of a blockchain application. Singhal et al. (2018) list areas of blockchain technology usage as finance, insurance, banking, healthcare, government, supply chains, IoT (Internet of Things), and media and entertainment but also add sharing economy examples like Uber and Airbnb. Yet, they highlight that those sharing economy examples are not pure applications of decentralization. Blockchain would be a promise to transform them into peer-to-peer examples.

Bambara and Allen (2018) mention about blockchain as a foundational technology which has significant value for global supply chains, financial transactions, asset ledgers, and decentralized social networking in terms of efficiency. They gather practical use cases under the topics of financial technologies, sharing economy, real estate, identity, law practices, decentralized file storage, decentralized autonomous organizations, cloud computing, and gambling and betting. From the above information, it is deduced that blockchain will have it place in different areas to be practically implemented. In summary, blockchain has practical application areas such as law, insurance, finance, and supply chain.

a. Law: Blockchain technology with its feature of smart contracts is expected to change the way how law would be practiced in the future. Lawyers would be expected to be technologists and would act as mediators in the process of dispute resolution or any agreement come to actualization between parties. Self-executing contracts will affect the dispute resolution in a way that they need to be dynamic. In this context, blockchain technology and distributed ledger technology should be deeply understood by the mediators so the process is fulfilled correctly and needs of clients are satisfied (Bambara and Allen 2018). Global legal services are forecasted to grow to $1,011 billion by 2021. While the industry grows, manual, laborious tasks take up the bulk of the work. Time wasted in document creation and management activities costs firms $9,071 per lawyer a year, equivalent to a 9.8 percent loss in the firm's total productivity. Blockchain solutions, at this point, are expected to decrease the wasted time and automatize processes by contributing to the system with features of accessibility, transparency, cost savings, speed, efficiency, and data integrity. Some possible applications of blockchain technology in legal area are listed as Electronic Signatures, Intellectual Property, Property Rights, Chain of Custody, Tokenization, Decentralized Autonomous Organizations (DAO), Limited Liability Autonomous Organizations (LAO), Automated Regulatory Compliance, Machine to Machine Payments, Blockchain-Based Arbitration System.[5]

b. Insurance: Insurance sector is a competitive business where customers seek high value and excellent experience from the services they get. Blockchain technology is promising for this sector in a way that better products and markets can be built upon this technology with benefits of efficiency gain, cost saving, transparency, faster payouts, and fraud mitigation. Smart contracts enable low cost for transactions which means products to be delivered competitively within a developing environment. Blockchain's foreseen applications for insurance sector would be listed as registries of high-value items and warranties; know-your-customer (KYC) and anti-money laundering (AML) procedures; parametric (index-based) products; reinsurance practices; claims handling; distribution

[5] Consensys, Blockchain in the Legal Industry, 2020, [Online]

insurance methods; peer-to-peer (P2P) insurance models.[6] Drescher (2017), in his book, states that sectors like insurance would be developing blockchain solutions, and smart contracts are the most promising tools for this development by giving flexibility to e.g., issuance of insurance payments for happening of damages or complex events. He also mentions about managing ownership rights or how to implement the rules within a blockchain world would have a huge impact in upcoming years. However, to reach a perfect automated smart contract in insurance, blockchain needs accompanying technologies like internet of things (IoT). With the help of such technologies the oracle problem, external data is meaningless in blockchain network, could be solved and network can act on insurance claims automatically (Bambara and Allen 2018; Gupta 2017; Usta and Doğantekin 2017).

c. Finance: Satoshi's paper on Bitcoin is a clear pathway how blockchain can be an alternative to the current financing systems. Many finance activities including stock, private equity, crowdfunding instruments, bonds, mutual funds, annuities, pensions, and all manner of derivatives are being redefined by blockchain technology developers. After Bitcoin, new projects like Ripple are initialized in the area of banking and finance (Swan 2015). Gupta (2017), on the other hand, gives use case examples for financing sector as commercial financing, trade finance, and cross-border transactions. In commercial financing IBM is one of the initiators to transfer all information regarding 4,000 partners on the blockchain and presented as distributed ledger. Decentralized Finance (DeFi) is the new paradigm against current system operated by mediators. With blockchain technology, intermediaries are to be eliminated since peer-to-peer network structure does not require them to actualize transactions between parties. Trust between unknown parties is built by the network mechanism and as a result, more efficient, innovative, and borderless environment is provided. Main uses of DeFi are listed as decentralized currencies, payment services, fundraising, and contracting (Chen and Bellavitis 2020).

[6] Consensys, Blockchain in Insurance, 2020, [Online]

d. Supply chain and logistics: Supply chain is a complex structure where a lot of parties are needed to manage flows of goods, services, money, and information. Therefore, traceability of supply chain is an important aspect to manage these flows in a correct way. There occurs lots of inefficiency, latency, and failures, and these incur high costs to the supply chains. A worldwide survey results show that the main challenges in supply chain are visibility (21.1 percent), fluctuating customer demand (19.7 percent), inventory management (13.2 percent), and coordinating operations across multiple sales channels (11.8 percent). Major concern on supply chain visibility is an important notice for all technology developers because visibility concerns are closely related with the quality and availability where solutions for improving traceability of the flows through whole process makes extremely important contribution to the sector.[7]

   Some examples to the defective side of current supply chains would be given as (i) half of the transportation cost incurs for documentation in container shipping, (ii) labeling mistakes in seafood increased up to 87 percent during 2010-2012, (iii) PwC report says that global economy gains 2 percent of its revenue from forgery,[8] (iv) global counterfeit value has increased up to 1.2 trillion dollars, (v) in 2020, value will reach 2 trillion dollars which represents 2 percent of worldwide trade, (vi) 5-6 percent of EU and USA imports are estimated to be counterfeit, (vii) it is observed that US Customs and Border Patrol (CBP) can only detect 1 percent of imports which are counterfeit.[9], (viii) Turkey is listed as 6th for export tendency of counterfeit goods. It is the 3rd country to capture counterfeit and pirated goods after China and Hong Kong.[10]

   Currently used examples of technology for transparency in supply chain area are Radiofrequency Identification (RFID), Quick Response Code (QR), Electronic Product Code (EPC), Enterprise Resource Planning (ERP), Sensors, and so on. Yet, there are issues where these technologies alone are not able to provide

[7] Technowlogi, 2018. 2018 EFT Supply Chain Study, California: USA
[8] Consensys, Blockchain in Supply Chain Management, 2020, [Online]
[9] Coates, R., 2019. Are there counterfeits in your global supply chain?. [Online]
[10] OECD/EUIPO (2019), Trends in Trade in Counterfeit and Pirated Goods, Illicit Trade, OECD Publishing, Paris/European Union Intellectual Property Office. https://doi.org/10.1787/g2g9f533-en

effective solutions. Especially security and trust topics in supply chain management have a lot of ways to be resolved with these technologies. As long as the data is centrally managed, these negative issues on each supply chain will continue to be pop-up at the tables of managers. From the customer side, on the other hand, verifying the safety of products they consume will be a hardship within these conditions (Chen et al. 2017). Blockchain, at this point, is very promising to the supply chains in terms of traceability, transparency, and traceability. Smart contracts are very useful to enable provenance of goods and services both upstream and downstream on the supply chain. Tracking of supply chain flows are expected to be better and easier so, blockchain could be a solution to the verification and trust issues. Blockchain is also expected to contribute to cost efficiency and consumer experiences since it creates a real-time visible and participatory environment within supply chain.[11]

2.1.5 Major Blockchain Platforms

Blockchain platforms are those with open or private source codes where developers or project builders can utilize to initialize their projects. Some are open source while others are private for business purposes (Usta and Doğantekin, 2017). They all provide an environment for blockchain applications, decentralized applications (dApps) as another name. These platforms are a way to the application of use cases in different sectors. There are several conditions project developers need to consider while choosing the platform they will base on. Not limited to but in general, these conditions can be listed as (i) is the platform being developed continuously? (ii) what is the required blockchain type? (iii) what programming language does it use? (iv) popularity of blockchain platform, (v) consensus protocol of blockchain platform, (vi) which functions (security, scalability, transparency, etc.) are required for the project?. Bitcoin is the first example of these platforms. Then, many others are developed according to the purposes and requirements of projects. The most popular ones are including Ethereum, Hyperledger, Ripple, IBM Blockchain, Microsoft Azure Blockchain, Quorum, and Corda.[12]

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[11] Consensys, Blockchain in Supply Chain Management, 2020, [Online]
[12] LeewayHertz, 2020, Top blockchain platforms of 2019, [Online]

a. Bitcoin

Bitcoin, is an open-source platform that is built for peer-to-peer payment transactions. Bitcoin is an innovative alternative to banks and intermediaries like Western Union. There are numerous inefficiencies with these current systems e.g., transaction fees are high, duration a transaction is finalized is long, not fully transparent, and transactions depend on a central authority. Bitcoin platform overcomes these inefficiencies. Whole system is built around participants where the transactions are actualized by consensus of participants. There is also an incentive mechanism using PoW to ensure the continuity of the network. Besides, it also serves as decentralized distributed ledger where data can be recorded immutably and securely (Usta and Doğantekin 2017). Nakomoto (2008) summarizes what Bitcoin serves for in the Whitepaper as "A purely peer-to-peer version of electronic cash would allow online payments to be sent directly from one party to another without going through a financial institution."

b. Ethereum

Ethereum is a state machine which allows transactions within a reliable messaging framework.[13] It has proof of work mechanism as Bitcoin does, however it is being developed to have proof of stake mechanism in Ethereum 2.0 to enhance performance of the network. On top of enabling transactions, Ethereum comes with many other applications such as building decentralized autonomous organizations (DAOs). The best example of it is smart contract application that is programmed to perform required actions between parties of a contract. It is an important development, because it allows audit and fraud free transactions to be actualized without a need of intermediaries (Karame and Androulaki 2016, p. 174). Especially, for businesses that majorly rely on contracts between parties, Ethereum structure is very essential source and tool to build and manage relationships. It is a promising open-source platform for transforming supply chains if the performance issues and scaling issues could be properly handled by the network developers.

[13] Wood, G., 2019, ethereum.github.io, [Online]

c. Hyperledger

Hyperledger is another open-source community that is devoted to build blockchain projects for enterprises. The community consists of more than 230 organizations gathered under the roof of the Linux Foundation. It is designed to fulfill different expectations and requirements of enterprises. For example, some enterprises value trust issues while other does decentralization. Therefore, Hyperledger has a philosophy of answering those varying needs within frameworks of modularity, high security, interoperability, agnosticism, and completeness. These features attract many enterprises from finance to supply chains. The community has already served different sectors with customized projects such as IBM Food Trust developed for tracking food from soil to fork. While developing accustomed projects, Hyperledger offers different frameworks (Burrow, Fabric, Indy, Iroha, Sawtooth) and tools (Caliper, Cello, Composer, Explorer, Quilt) for different sectors that are designed according to the needs.[14]

d. Corda

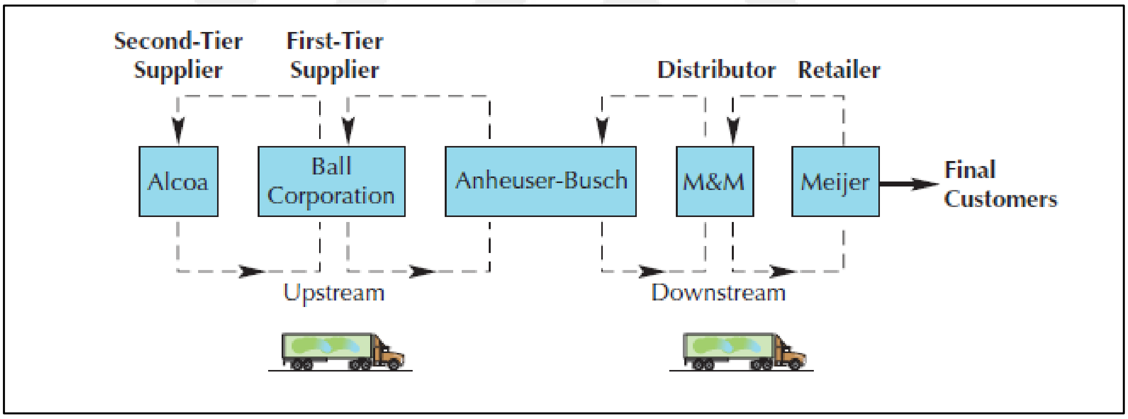
Two years after Hyperledger release, Corda, another enterprise blockchain development community has been launched in 2018 to provide a distributed platform for recording and processing shared data. Corda platform especially insists that it is designed for enhancing business agreements between trading partners. Therefore, they have developed different perspectives to the enterprise blockchain projects as they propose smart contract logic presenting pre-agreed rules, notary pools for managing transactions and consensus, and flow framework which is genuine feature to Corda for easing the processes between partners. Although it resembles to Hyperledger and Ethereum in some ways, it differentiates as the platform presents a one node infrastructure that enables interchangeable usage and common area for all parties where networks can interoperate each other and decrease their costs.[15]

[14] The Hyperledger White Paper Working Group, 2018, [Online]
[15] Brown, R. G., 2018. The corda platform: An introduction white paper. [Online]

2.2 SUPPLY CHAIN MANAGEMENT

"A supply chain is dynamic and involves the constant flow of information, product, and funds among different stages." (Chopra and Meindl 2016, p. 14). The statement by Chopra explains the supply chain's complex structure where it includes many parts and stages. As the name expresses, it is a chain of flows or stages where one triggers the other. Supply chain management is the holistic view of planning, managing, and controlling all the activities within this chain of flows to make much of the value for customers to compete in business life. (Bozarth and Handfield 2013, p. 7). A simple model of supply chain for Anheser-Busch is displayed below Figure 2.6 for us to better understand the parts forming the chain:

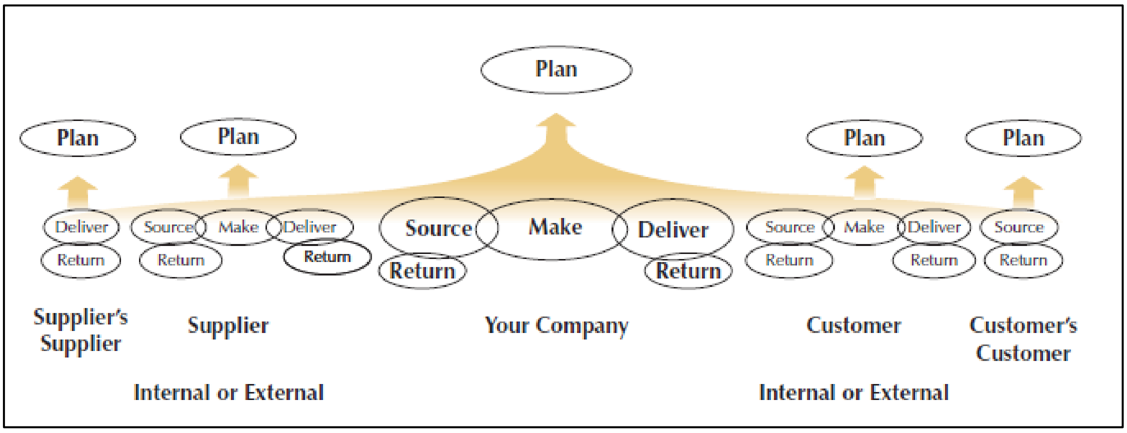
Figure 2.6: Anheuser-Busch's supply chain model



Resource: Bozarth, C. and Handfield, R., Introduction to Operations and Supply Chain Management, 2013, p. 6

From Figure 2.6, we see that there are major touch points in a supply chain which are supplier, distributer, retailer, and customer. There is another perspective to supply chain management proposed as SCOR Model - Supply Chain Operations Reference Model – approaching to the concept from a broader view where it displays the processes, relationships, and metrics within a standard supply chain. SCOR Model shown in Figure 2.7, reveal the major parts of supply chain as well as the activities take place within each phase. It starts with planning and follows with sourcing, making, delivering, and returning internally and externally valid for each touchpoint (Bozarth and Handfield 2013).

Figure 2.7: SCOR model by supply chain council



Resource: Bozarth, C. and Handfield, R., Introduction to Operations and Supply Chain Management, 2013, p. 6

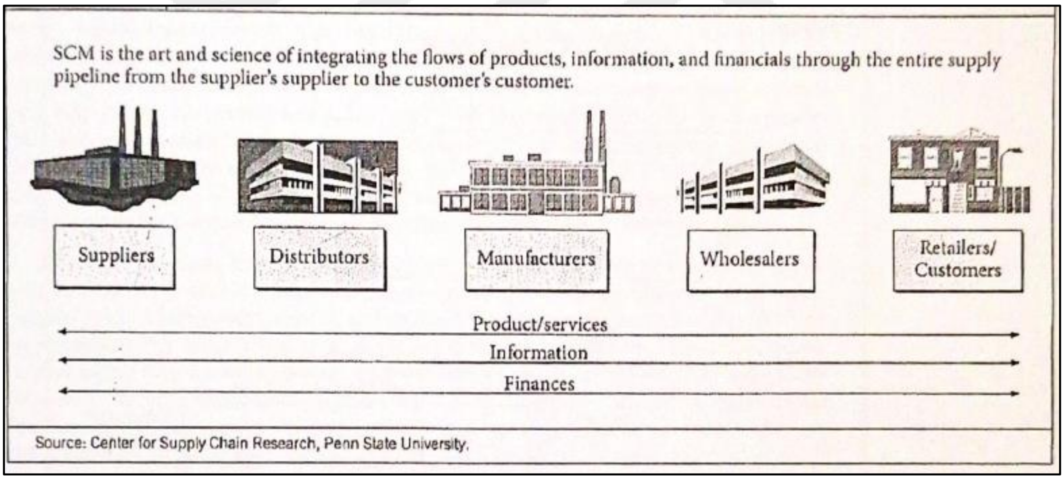
Along with the industrialization, supply chain management has gained important role to minimize costs incurred to supply demand in a competitive environment. It experienced major shifts on the way to the global world changing around us. Traditional supply chain models had to adapt to the globalization driven by technological developments. Developing information systems has changing the supply chains to better answer the needs of customers as well as optimizing the operations within chains. Processes taken months previously take days and hours today thanks to systems enhancing each and every day. Before we deep into objectives and the developments for supply chain, below are various definitions for the concept from different perspectives where they find a middle ground in purpose to fulfill customer demand in the best way possible. “A supply chain is a global network of organizations and activities that supply a firm with goods and services.” (Heizer et al. 2017, p. 6) “The term supply chain conjures up images of product or supply moving from suppliers to manufacturers to distributors to retailers to customers along a chain.” (Chopra and Meindl 2016, p. 14) “Supply chains are boundary spanning and require managing three flows – products/services, information, and financials (cash).” (Coyle et al. 2013, p. 27)

2.2.1 Supply Chain Management Objectives and Issues

Chopra and Meindl (2016) defines SCM’s objective clearly by giving the formula of value created through a supply chain. Every supply chain’s aim is to maximize that value while minimizing costs. Formula to the value, supply chain surplus in other name, is the difference between customer value and supply chain cost. In this formula, customer value means the value customer gives to the final product or service in terms of max. price s/he pays while the cost means the costs aroused throughout the whole processes of the chain. Main aim is to increase profitability of the whole chain by increasing the amount left from supply chain surplus.

In other words, increasing profitability lies under the optimization of costs regarding all activities and processes displayed on SCOR Model Figure 2.7. Therefore, dynamic structure of supply chains should answer the measures of quality, speed, dependability, cost, flexibility, and sustainability to achieve the main objective to max profit while min cost (Kshetri 2018). Key to achieve this objective is managing flows that link the chain.

Figure 2.8: Integrated supply chain framework



Resource: Coyle, et. al., Managing Supply Chains: A Logistics Approach, 2013, p.17

Figure 2.8 displays the major components in a supply chain and the flows followed along. Managing these flows in the most optimized way is the main purpose of supply chain management where there created value for customer in each phase for providing the best fit of demand.

However, achieving this goal is not always painless. There exist issues and challenges to the supply chains due to its complex and multi-staked structure. Heizer et al. (2017) explains the issues that affect efficiency and integration of supply chain as local optimization, incentives, and large lots. Planning and acting individually in these three issues harm the whole chain by causing fluctuations in overall flow resulting in bullwhip effect triggered by the misplaced inventory orders. Coyle (2013), moreover, gives a broader list of topics to the issues faced by organizations. Those issues include; (i) supply chain network which needs to be agile on rapid changes, (ii) complexity which comes with the globalization and consolidation should be simplified, (iii) inventory deployment which relates to bullwhip effect, (iv) information which needs to be synchronized and analyzed properly to take better decisions, (v) cost/value ratio to achieve profit in every stage for a whole gain, (vi) organizational relationships regarding internal and external collaboration for a fast and right flow of processes, (vii) performance measures to see the picture clearly and evaluate correctly, (viii) technology which opens rooms for improvements when implemented correctly, (ix) transportation management for a well-functioning supply chain, and (x) supply chain security regarding all possible threats to the supply of goods/services from natural disasters to terrorist attacks.

2.2.2 Blockchain in Supply Chain

Under supply chain and logistic subheading, it is already been stated that the supply chain is an important application area for blockchain technologies, and the applications have a room for improvements in the sector if the costs could be decreased for it to be used widespread. From both technical and practical perspectives, studies and developments are being centered upon how blockchain can shape the future of supply chain. There are different studies conducted in different sectors to understand the applicability of this game changing technology in supply chains, e.g., automotive, pharmaceuticals, food, agriculture, energy, etc. Blockchain technology is promising in various aspects for supply chains like traceability, security, integration, transparency, etc. Therefore, it opens many doors to the researchers and practicians to find out the benefits and obstacles of the technology of future along with others like IoT and AI.

Tse et al. (2017) in their study focus on the food supply chain in terms of information security by proposing a blockchain application in comparison to the current system in China. Starting with the questioning traceability and reliability of current system in supply chain and the role of governments, businesses, and consumers, they suggest a decentralized food supply chain authentication model which shows the nodes and the way they are related to each other. They defend that blockchain can change the way information is interchanged safely and transparently within supply chains, it provides authenticated transactions which cannot be denied, and finally traceability is easier with blockchain technology. Sternberg and Baruffaldi (2018), have a broader approach to the concept as they ask if the technology will affect supply chain in a disruptive way. They examine the research and initiatives in business life and conclude that blockchain has a huge potential for supply chain area along with difficulties of application in real life. A case study in agriculture area, proposes a blockchain model which also improves the supply chain in terms of circular way. They suggest a multi-agent system utilizing smart contracts to monitor and verify orders (Casado-Vara et al. 2018).

Information flow within supply chain is essential to any businesses all over the world. Keeping a good track of this flow make the companies to be in the winner level. Benton et al. (2018) believes that the blockchain technology is not a whim and has important implications for supply chain traceability if developers and companies pay enough attention to the technology. They figure a hypothetical model for food production and distribution within a consensus environment. Given the Hyperledger example, they think players in supply chain area have immense opportunities in developing ways to increase efficiency as IBM has found in their case study of Maersk that they could win 10 percent efficiency in operational costs. Another traceability model is proposed on Ethereum Virtual Machine to track and trace products information in each production processes where a transparent and comprehensive production information is available to the company (Westerkamp et al. 2018). A case study of coffee supply chain – one of the most consumed products – proposes development of a blockchain model for Burundian coffee sector. Results of the study have important implications for coffee traders in Burundi since the most important issue is lack of certified treaders in the sector, which makes it hard to trace flows, ensure sustainability, have more market access, and set high prices for producers especially (Thiruchelvam et al. 2017). Aviation case study researchers also believe that blockchain is promising for tracking and integrating the documentation in airline industry as they deeply analyze RFID implementation of Airbus and suggests blockchain as an alternative to the current system (Santonino III et al. 2018). Abeyratne and Monfared (2016), in their article, also studied blockchain based supply chain for manufacturing industry for cardboard boxes. From their hypothetical blockchain scenario, they deduce that proposed model can provide large amount of data for both consumers and producers, which can enable them to take better decisions. Feedback from customers, and information gathered during processes could improve organizations with regard to design, and manufacturing. They also suggest that smart contracts along with the proposed blockchain model can prevent frauds and misplacements which ensure security and safety in return. Tian (2017) also examined blockchain technology for food supply chain traceability considering safety of food. He proposes a system based on blockchain and IoT technologies which he calls as BigchainDB which is an example application to enhance supply chain traceability and reliability of food we obtain. Akyuz and Gursoy (2019) also express positive findings of their study as they support that blockchain technology will enable true and secure transactions as well as visibility where parties can trust each other. This is believed to be the facilitator of supply chain transformation into a digital, trustable, and traceable one.

Queiroz and Fosso Wamba (2019), on the other hand, conducted an empirical study on blockchain adoption in India and USA with regard to technology acceptance model (TAM). Their findings express important implications for practitioners in field in terms of challenges in adopting this new technology. They have found that facilitating conditions for blockchain technology adoption are important barrier in emerging countries, and it needs a lot of struggle and cost to build infrastructure to meet facilitating conditions such as IT structure. They also imply that it is essential to correctly analyze impact on user productivity. A recent study by Casino et al. (2020) proposes a blockchain model for dairy sector and findings support blockchain adoption in positive ways. They have found that their model has important implications in terms of enhanced trust, efficiency, quality, and resilience in dairy food chain they studied on. However, they also state that the technology has drawbacks since it generates immense amount of data and brings issues of scalability which influence performance of supply chain overall.

Among blockchain for supply chain studies so far, sectors examined include: Agriculture (Caro et al. 2018; Hua et al. 2018), Automotive (Fowler 2018; Sharma et al. 2018), Aviation, Commerce (Chen et al. 2017; Notheisen et al. 2017), Energy (Ashley and Johnson 2018; Mylrea and Gourisetti 2018), Food (Casino et al. 2020; Dinesh Kumar et al. 2020; Feng et al. 2020; Guido et al. 2020; Rogerson and Parry 2020; Tan et al. 2020; George et al. 2019; Galvez et al. 2018; Keller and Kessler, 2018; Kim and Laskowski, 2018; Kim et al. 2018; Tian 2017; Tse et al. 2017; Tian 2016), Logistics services (Arumugam et al. 2018; Imeri and Khadraoui 2018; Meng and Qian 2018; Ngamsuriyaroj et al. 2018; Verhoeven et al. 2018; Foerstl et al. 2017), Manufacturing (Mondragon et al. 2018; Nakasumi 2017), Maritime industry (Gausdal et al. 2018; Xu et al. 2018), Military (Zaerens 2018; Sudhan and Nene 2017), and Pharmaceuticals (Sylim et al. 2018; Tseng et al. 2018; Bocek et al. 2017; Apte and Petrovsky, 2016). Focus areas of these studies are blockchain integration into supply chain, impact of blockchain on supply chain performance, security, transparency, traceability, and visibility. From the sectors listed, food is the most studied sector and logistics services following it. The most studied topic is supply chain traceability and transparency.

Blockchain is not only getting popular in academic field but also in practical field. There are various case studies conducted by large companies to understand the merits of this technology. There are different implementations of blockchain technology on supply chain from professionals. Below are some early adopters and famous examples from business field:

a. IBM Case Studies: IBM is one of the pioneers to implement blockchain technology in different processes and come up with a product called IBM Food Trust for enhancing food chain in companies. IBM Food Trust is a blockchain ecosystem developed for food sector including food chain stakeholders from producers to the consumers. All related information, e.g., certificates, temperature, location, is accessible through the system. They provide software-as-a-service (SaaS) and highlight that the service prominently provides supply chain transparency and trust as it enables safety, sustainability, shared information, and speed. The solution is developed on Hyperledger Fabric by

Linux Foundation to take benefit of large developer network and open-source information. They prove that the customers can track products in 2.2 seconds, which is an important enhancement in operational speed for companies. IBM Food Trust is now giving service to 7 different segments of agriculture commodities, grocery, restaurants, food logistics, fresh produce, manufacturing, and seafood.[16] For fresh produce, e.g., pilot study with Walmart to track Avocados in their supply chain decreased the 7 day to 2.2 seconds thanks to blockchain solution as we know 50 percent to 60 percent average loss through the supply chain.[17] Another pilot study with a local provider of hamburger patties, sausages, and other similar product to retailers and restaurants has shown the importance of visibility and real-time data monitoring in beef logistics for delivering healthy and quality products to the industry.[18]

b. Oracle Blockchain Solutions: Oracle is another company providing blockchain solution as service on Hyperledger Fabric. It is also a SaaS application offering different solutions like cloud service, enterprise edition, and intelligent track and trace for supply chains. Important features of intelligent track and trace service are promising end-to-end visibility, risk aversion, fast implementation, fully integrated connection, and monitoring of product conditions. It is a preassembled blockchain where can be integrated to the existing applications within minutes. It enables to work on other Hyperledger Fabric nodes with its multicloud feature. Oracle reveals the benefits of integrating blockchain into the operations as diminishing the conflicts between parties, keeping records and transactions safe, providing more paperless transactions, and easing the monitoring of commodities.[19] They have three cases for different applications in intelligent track and trace product, which are (i) track of food for temperature during delivery, (ii) a network to build trust in beer brewing, and (iii) equipment tracking of reverse logistics.[20]

[16] IBM, IBM Food Trust. A New Era for the World's Food Supply, 2020, [Online]
[17] IBM, Fresh Produce on Blockchain, 2020, [Online]
[18] IBM, Food Logistics on Blockchain, 2020, [Online]
[19] Oracle, Oracle Intelligent Track and Trace, 2020, [Online]
[20] Oracle, Oracle Intelligent Track and Trace, 2020, [Online]

c. Provenance: Provenance is an enterprise having a vision to transparentize supply chain processes by enabling businesses and consumers to have knowledge on the source, journey, and impact of products. As knowledge is power, they highlight the importance of having access to the valuable information created within supply chains, and they carry a mission to make consumers to be eligible for knowing what they really buy.[21] They serve over 200 business customers in food and beverage industry to track the journey of their products. They also give service to different sectors like fashion and beauty. Some case studies they implemented so far are (i) Princess Group to track fish, (ii) Napolina for preventing fraud and illegal labour in tomato supply chain in Italy, (iii) Cult Beauty for giving reliable information to the customers on brands (iv) Royal Auping for building a circular economy model in textile sector. More examples are exhibited on corporate website with results.[22]

d. Fetch.ai: Fetch.ai is relatively new company operating in services. They offer artificial intelligence and blockchain solutions. They provide a network of open access, tokenized, and decentralized machine learning to support a decentralized digital economy infrastructure. They are an AI lab based in Cambridge to develop secure sharing, connection, and transaction of data worldwide. The network they built includes autonomous agents working for advantage of suppliers and consumers.[23] Some use cases of Fetch.ai are (i) smart city application in Germany aiming to decrease resource consumption and carbon emission – 34,000 ton/year, (ii) decentralized exchange of commodities like steel, base metals, and other to increase liquidity and to alternate new ways to supply chain finance, (iii) providing a platform for collective learning – first example in healthcare, (iv) intelligent supply chains that is able to detect patterns and capture data to optimize efficiency. They also build cases in publication field, decentralized train network, smart homes, energy, smart mobility, parking, and congestion solutions.[24]

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[21] Provenance, We Live in the World We Buy into, 2020, [Online]
[22] Provenance, Case Studies, 2020, [Online]
[23] Fetch.ai, Artificial Intelligence for Blockchains, 2020, [Online]
[24] Fetch.ai, Use Cases, 2020, [Online]

Paul Brody, EY Global Innovation Blockchain Leader, clearly states the power of blockchain in transforming supply chains as:[25] "Through blockchains, companies gain a real-time digital ledger of transactions and movements for all participants in their supply chain network. But don't let the simplicity of the tool overshadow how transformational it is." In his report, he explains how advantageous blockchain can be for supply chains and list the advantages as (i) more visible procurement process and more savings thanks to the visibility that digital ledger provides for companies to avoid extra costs attached to audit process; (ii) blockchain would allow companies to have accurate, verifiable data and analysis which could enable advanced forecasting and less inventory; (iii) better track of payment records enhancing financial flow in supply chains thanks to smart contracts; (iv) shared network of information gives participants power of control over fraudulent behavior.[26]

Another report prepared by Microsoft also emphasizes on supply chain transformation with blockchain technology. Basically, they group three benefits of blockchain for supply chain as (i) provenance attestation, (ii) environmental monitoring, and (iii) dispute resolution. In terms of provenance, suppliers are able to be recognized and gain advantage in market by certifying their processes and products quality; retailers are able prevent risk of forge products and enable consumers to trust them; consumers are able to track products they consume. In terms environmental monitoring, companies are able to track specific features that should be ensured for products to be safely delivered to the consumer by the help of technologies like IoT. Companies can track information regarding temperature, humidity, damage, etc. levels of products so they can have control over impacts of product to the environment and consumer. In terms of dispute resolution, suppliers are able to track delivery information and assure retailers and consumers in case of disputes.[27]

Main advantages attached to the blockchain deployment in supply chain can be summarized as cost benefit, speed of transactions, dependability, flexibility, risk

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[25] Brody, P., 2017. How Blockchain is Revolutionizing Supply Chain Management, s.l.: Digitalist Magazine.
[26] Brody, P., 2017. How Blockchain is Revolutionizing Supply Chain Management, s.l.: Digitalist Magazine.
[27] Microsoft, How Blockchain will Transform the Modern Supply Chain, 2018.

reduction, and sustainability with regard to supply chain objectives (Kshetri 2018). In terms of speed, blockchain can provide companies a system of networks where they can easily access information, documentation, and other resources generated within chain (White 2018; Nakamoto 2008). In terms of cost, blockchain helps to decrease cost by enabling companies to track payments, inventory, reverse logistics processes and automatic audit of transactions (Cerasis 2018; Kshetri 2018; Lauslahti et al. 2017; Fritz and Schiefer 2009). In terms of sustainability, blockchain is a useful tool to identify fraudulent behavior and provide trustable data of provenance on transactions and network participants[28] and (Foerstl et al. 2017). In terms of dependability, blockchain technology provides a decentralized network of participants where all flows within supply chain are visible to those participants[29] (Nakamoto 2008). In terms of flexibility and risk reduction, blockchain assures the security and dynamic structure to provide value and quality to the consumers and other network participants (Kshetri 2018). Immutable structure of blockchain builds trustable environment and information for all parties within network (Akyuz and Gursoy 2019). Encryption and consensus mechanism allows participants to have secure and reliable data regarding transactions, participants, sources of information (Perboli et al. 2018). Decentralized shared ledger generates a collaborative environment for participants where no intermediaries are needed to exchange information.[30] Ünlü (2018), in her thesis, list the benefits of blockchain technology for supply chain as traceability, single source of truth, compliance, intermediary, accountability, synchronization, visibility, and security.

However, as every technological development, blockchain also comes with challenges. Briefly we can list these as technical limitations, scalability issues, efficiency and maintenance issues, technology adaption problems, lack of regulative instruments, lack of qualified people in implementation, finding the right platform to deploy, and excessive computing power needed for the technology to operate (Min 2019; Agarwal 2018; Lourenço Costa 2018; Perboli et al. 2018). Companies need standardized systems mostly to predict possible deficiencies and problems, but blockchain technology lacks standards

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[28] Deloitte, 2017. Continuous Interconnected Supply Chain-Using Blockchain and Internet of Things in Supply Chain Traceability, s.l.: Deloitte.
[29] Ambrosus, White Paper V8, 2017, [Online]
[30] DHL & Accenture, 2018. Blockchain in Logistics: Perspectives in the Upcoming Impact of Blockchain Technology and Use Cases from Logistics, Troisdorf: Germany.

as it is a developing technology. Changes and improvements in the technology could give hardships for the companies to compatible standards of collective and cooperative operations (Lourenço Costa 2018). Lack of understanding of technology is also another obstacle for blockchain implementation. A new solution initiative is proposed as technology improved and companies might lack the best version, they can benefit from (Agarwal 2018). Blockchain technology is not sustainable in its nature as well due to high energy it needs to operate (Perboli et al. 2018).

2.2.3 Food Supply Chains

Food as our basic need has an important place in our lives. Also, it is important for sustainable world in terms of waste it creates. Food Supply Chain Management at this point turns into a significant duty for all companies operating in this field. Food supply and demand in the market is tightly related to the world population growing at annual rate of 2 percent. World population has reached to 8 billion approximately by 2020. Food consumption has an increasing growth rate compared to population thanks to the factors of income growth and change of consumer preferences. Income growth especially has led to consumption increase in high value products like meat and dairy-food.[31] Population is expected to grow up to 9 billion till 2050 and forecasted impact on food production will be 60 percent thanks to the rise of food consumption/capita and calorie demand/day (Runyan and Stehm 2019). Value of agricultural production in 2018 reached up to 2 billion USD worldwide while value added increased to 68 percent. Agriculture constitutes the 4 percent of global GDP today.[32] Food market is segmented into 13 different groups under classifications of processed and unprocessed food. The largest share within these segments belongs to Confectionery & Snacks with 17 percent. Meat (15 percent), Bread & Cereals (14 percent), and Dairy Products & Eggs (11 percent) follow the Confectionery & Snacks. Revenue from food production constitutes 7 trillion USD around the world, and China is the top consumer of food in 2019. Revenue from food worldwide is expected to rise up to 9 billion USD by 2025. Consumers are gaining awareness on health and sustainability issues pertained to food after terrible food scandals in recent years.

[31] European Commission, 2019. Global Food Supply and Demand-Consumer Trends and Trade Challenges, s.l.: European Commission.
[32] FAO, 2020. Statistical Yearbook-World Food and Agriculture 2020, Rome: Italy.

Especially, consumers in Europe and China are trying to avoid consuming artificial flavors and sweeteners. Consumers are more demanding for fresh food compared to packaged food, and consumption is shifted to out-home services.[33]

Briefly, food supply chain includes the act of delivering food from source to the consumer in an effective and safe way. Mostly expressed as processes from farm to fork pertaining challenges of perishability, quality, safety, short shelf life, and specific requirements during delivery and storage to provide high quality and security to avoid any health issues (Bortolini et al. 2019). Major actors in food supply are consumers (the largest), farmers, food service and retail, and food and beverage processing industry in EU. There are 11 million farms in agricultural production and 300 thousand businesses in food and drink sector. Nearly 3 million companies in food delivery and service sector serves for 500 million customers in EU.[34] 4.4 million mt of food delivered in 2019 according to World Food Programme report on supply chain.[35]

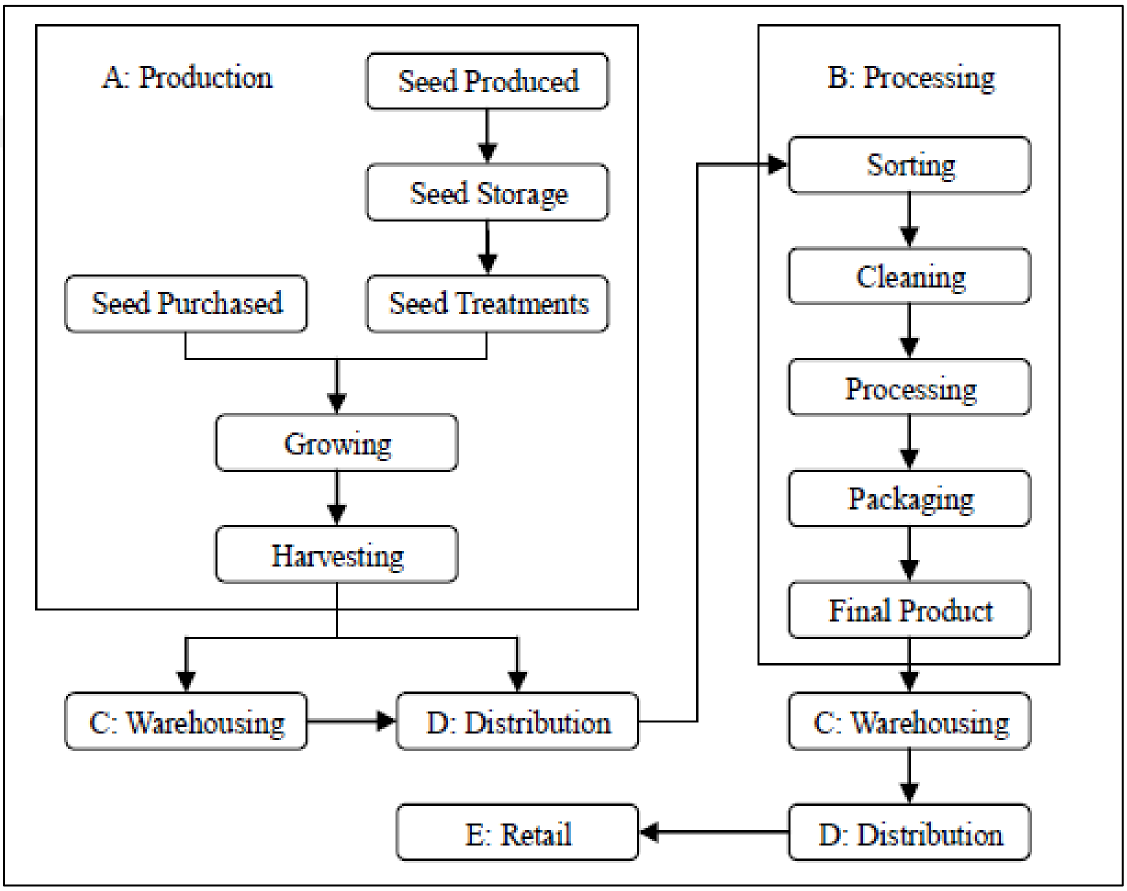
Recent scandals and infringements in food safety protocols have drawn attention of researchers and institutions towards food supply chain issues. Trust against food suppliers has damaged as new problems occur although technological advancements like RFID and sensors. Centralized structure of food chains is open invitation to information asymmetry, fraud, corruption, and attacks which affect human well-being. Methods like Hazard Analysis and Critical Control Points (HACCP), Product Traceability Systems, et. are very helpful to provide these problems but not enough to overcome precisely (Tian 2017). In food supply chains, formation of regulations and standards on product quality and pricing is very essential to provide security. A good monitoring and control over food supply chains under regulations internationally and nationally bring benefits to the companies and consumers in terms of trust between entities (Kniepert and Fintineru 2018).

Building a sustainable food supply chain is very essential to the quality, safety, transparent delivery process, access of healthy and affordable food, incentivizing the use of local materials and resources, improved procurement, decrease hazardous impact on

[33] Frimpong, J., 2020. Food Report 2020, s.l.: Statista.
[34] European Commission, The Food Supply Chain, 2020. Food Safety: Overview, 2017, [Online]
[35] World Food Programme, 2019. WFP Supply Chain Annual Report, s.l.: WFP.

environment, decrease waste of water and energy, motivate renewable energy consumption, and decrease cost of production and distribution (Çetin 2014). Below, Figure 2.9 displays basic flows in food supply chain from production to retailer. The flow starts with production including seed and harvesting, continues with processes of sorting, cleaning, packaging, etc. to be stored and distributed along the chain, and finally it ends up in retailer to be delivered to the end customer.

Figure 2.9: Simplified food supply chain flows



Resource: Tian, F., A Supply Chain Traceability System for Food Safety Based on HACCP, Blockchain & Internet of Things, 2017

2.2.4 Food Safety

Food safety is critical to human health and sustainability. Unsafe food practices are particularly affecting people and environment in a bad way where statistics show that 220 million children per year suffer from foodborne diseases and 96 thousand of them lose their life. Economically, food related diseases cause losses in productivity by 95.2 billion

USD/year while treatment cost makes up to 15 billion USD. Contaminated food can cause 200 different health problems and more from brain damage to the cancer. 1 in 10 people of world population suffer from foodborne diseases while 420 thousand die per year. The most effected segment from food contamination is infants, elderly people, and children. Food related diseases are mostly caused by bacteria like salmonella, campylobacter, and E-coli, viruses, parasites – conveyed via food, animal, water, or soil, prions – causing Bovine spongiform encephalopathy (BSE), also known as mad cow disease, chemicals like natural toxins (can be found in mushrooms and cereals affected by mold), persistent organic pollutants (POPs) mostly contained in industrial processes, waste incineration, and animal food chains, and lastly heavy metals like mercury causing important damage in brain and organs and transferred through air, water, or soil. Consumer demand shift towards out-home eating and supply of various food options has had visible effect of food supply chains as they get more complicated and longer. International occurrence of food chains complicates and fastens the spread of food diseases. Global trade and climate change together have important implications for food safety issues.[36]

Food safety is included among Sustainable Development Goals now as it is a big concern for productivity, worldwide health, socioeconomic problems, and environmental agenda. Governments are the key players in initiating rules and regulations for food security affecting wellness of the public. However, it is not the government to be responsible for ensuring food safety. Producers, distributers, and even consumers should take responsibility to maintain public health through safe food practices. Duty of consumers here is to know what they eat by paying attention to the labels, ingredients, certifications, origins of products, etc., and proper cleaning, cooking, and storing of food are other habits they should obtain for preventing food caused diseases. Responsibilities of governments and other public institutions are could be listed as promoting sufficient systems and infrastructures for food chains, providing a collaborative network of communication among sectors affecting food safety, merging food security policies and frameworks, and considering global risks and taking local precautions. World Health Organization (WHO) one of the key players in food safety practices, puts objectives of global prevention, detection, and response to the health issues aroused by food safety problems. Building

[36] World Health Organization, Food Safety, 2020, [Online]

trust between consumer and supplier of food is an important duty of WHO. To achieve these objectives, WHO works with governments and institutions to build a legal framework for food safety and security. They (i) define standards, guidelines, and recommendations under Codex Alimentarius; (ii) identify and develop measures, evaluation tools for food supply chains; (iii) evaluate new technologies if they are safe or not; (iv) help to build trusted systems and frameworks; (v) communicate information during food outbreaks with collaboration of UN Food and Agriculture Organization (FAO); (vi) provide training and disseminate knowledge among public and producers; (vii) raise awareness of food safety by promoting national policy and programs in accordance with the International Health Regulations.[37]

The Codex Alimentarius, also known as Food Code, is developed by WHO determines the standards and guidelines for food practices. It mandates protecting health of consumers, ensuring fair trade, and promoting coordination of food standards. Codex Alimentarius Commission (CAC), founded in 1963 by FAO and WHO collaboration, is one of authorities in the area to ensure proper adoption and application rules and regulations of Codex. CAC currently has 188 member countries, 1-member organization (EU), and 237 observing organizations. The guidelines of Codex benefit many organizations, e.g., World Trade Organization (WTO) for international dispute resolutions and food fraud cases.[38]

European Commission, another player in food safety, also puts objectives to ensure food safety and animal & plant health in EU area by proposing “Farm to Fork” framework and implementing “Integrated Food Safety Policy in EU”. The framework is developed under The General Food Law (GFL) (Regulation (EC) No 178/2002) which is the roof for all food safety practices in EU. It is the base for definitions, requirements, assessment tools, and risk analysis for whole agri-food related sectors.[39] Main actions performed are (i) putting effective control systems and EU standards of food safety, quality, animal health, nutrition, and plant health into practice across their export network; (ii) collaborating with

[37] World Health Organization, Food Safety, 2020, [Online]
[38] FAO and WHO, 2020. Codex – What Next for Standards? Private Sector Looks Post-COVID-19 – Safe Food Handling Practices as Important as Ever, Rome: Italy.
[39] European Commission, The General Food Law: Fitness Check, 2018, [Online]

countries outside EU, European Food Safety Authority (EFSA), and international organizations to take proper actions against food safety issues and risks pertaining to food chains[40] EU food safety policy defines standards and actions including hygiene, animal health, plant health, and contaminants & residues through tools of Alert system for food and feed (RASFF), Animal tracing system (TRACES), EU pesticides database, and Plant health notifications and interceptions (EUROPHYT).[41]

Worldwide notice on food safety standards roots back to 1994 when World Trade Organization was established. Afterwards, other standards and authorities like Codex, GFL, CAC, EFSA, FAO, etc. has been developed to broaden the acceptance and applications of secured food practices. Those practices are briefly segmented into two topics as (i) Hazard Analysis of Critical Control Points (HACCP), and (ii) Traceability. HACCP is a system defining and measuring hazardous points in food supply chain from farm to fork developed in 1959 for NASA. HACCP is put into practice in Turkey in 1997 along with The Regulation for Production and Audit of Food. HACCP determines the critical points in processes related to food and ensures preventions beforehand. Traceability, on the other hand, focuses on each process involved in food production from seed to end product. Tacking the records and measures of production regarding food is important to ensure food quality and safety as it dig into all process of chain (planning, production, packaging, warehousing, distribution, and finally point of sales). Thus, it enables companies track the origin of end products supplied to the customers. Traceability is defined in Codex as the ability to find the traces of location, practice, and history of related material. International Standards Organization (ISO 9000:2000) also has similar definition for traceability as tracking the location, application, and history of product backward by determining the origin of raw material, process history, distribution, and location history after sales (Çetin 2014).

Food safety gets attention from academia as well. In one of the studies, agri-food sector is examined in terms of cold chain practices of China with comparison to other countries (Sun 2009). Another one focuses on evaluation of critical factors affecting chain

[40] European Commission, The Food Supply Chain, 2020. Food Safety: Overview, 2017, [Online]
[41] European Union, Food Safety in the EU, 2019, [Online]

performance (Chan et al. 2006). Bogataj et al. (2005), in their paper, examine the hygiene and quality factors while Manning et al. (2006) suggest that proper information system structure should be obtained to satisfy those factors. Some researchers claim responsibility of building framework and regulations to the governments for the circulation safe food around the world (Trienekens and Zuurbier 2008). Some other studies particularly focus on dairy food sector which is one of the most consumed food segments. Valeeva et al. (2005) suggest that dairy food chains are affected by mostly hazardous chemicals and bacteria, and effective control of those substances are vital to the safety of food chains. There are also case studies to examine food safety outbreaks in different regions (Chen et al. 2014; Kumar et al. 2011). Developing a reliable and sustainable system for food safety is always a silver bullet issue for both companies, governments, and institutions. Therefore, many studies are focusing on developing alternative solutions with different models as new technology options are improved like blockchain, IoT, RFID, etc. Tian (2017), e.g., one of them suggesting a traceability model based on HACCP with respect to emerging technologies like blockchain. New methods of tracing risks and hazards on food supply chains will be needed as studies support that consumers, retailers, and public institutions will be more demanding on the proof of safety for the food (Papademas and Bintsis 2010).

2.3 TRACEABILITY

"*Scientia potentia est*." – the famous Latin phrase translated as "knowledge is power." – has origins back to 16th century but still powerful and important from every aspect in business life as much as social life. Tracing knowledge back and forth in each step of our lives is inevitable to human nature. Therefore, traceability touches everyone from individuals to corporates, and governments. Having information regarding the history of the things we consume, or the impact we make on earth aftermath of our consumption is vital to understand the big picture around us. We have to consume and produce for the sake of existence. Unconscious practice of producing and consuming has serious side-effects that we should pay attention. At this point, traceability is essential practice to leverage power of knowledge overcoming difficulties regarding these side-effects.

From business perspective as well, traceability has high importance since it provides valuable insight on products, processes, financial flow, and inventory. Consumers challenge businesses to provide reliable information on the products and services they offer. People are demanding more information for the origin of products they consume as scandals emerge in different sectors influencing human health. Food is one of them.

Traceability of food is a major concern in today's world since it is the basic need for human vitality. Globalization has made it more complex to track the origins of food we consume. Previously, people were growing their own food and knew where it comes from, what ingredients and raw materials it was exposed to. Now, the food produced in one place has ingredients from many different places to leverage low cost and high speed. Hence, traceability can be defined as capturing knowledge on products in every aspect from material to process. A good traceability record should answer what, when, where, and how questions. There are different definitions of traceability as new standards and systems are developed to enable better practices. Below are definitions from various institutions, standards, and researchers:

"The ability to discover information about where and how a product was made." or "The ability to find or follow something."[42]

"The ability to trace the history, application or location of an entity by means of recorded identification."[43]

> *"The ability to trace the history, application or location of an object. When considering a product or a service, traceability can relate to: — the origin of materials and parts; — the processing history; — the distribution and location of the product or service after delivery."*[44]

"The ability to trace and follow a food, feed, food-producing animal or substance intended to be, or expected to be incorporated into a food or feed, through all stages of production, processing and distribution."[45]

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[42] Cambridge Dictionary, Traceability, 2020, [Online]
[43] ISO 8402 1994 ISO Definitions. 1994. [Online]
[44] ISO 9000:2015(En) Quality Management Systems — Fundamentals and Vocabulary. 2015. [Online]
[45] Regulation (EC) No 178/2002, 2002. The European Parliament and of the Council. [Online]

"The ability to follow the movement of a food through specified stage(s) of production, processing, and distribution."[46]

"The ability to access any or all information relating to that which is under consideration, throughout its entire life cycle, by means of recorded identifications." (Olsen and Borit 2013)

> *"Traceability is the ability to track a product batch and its history through the whole, or part, of a production chain from harvest through transport, storage, processing, distribution and sales (hereafter called chain traceability) or internally in one of the steps in the chain for example the production step (hereafter called internal traceability)."* (Moe 1998)

> *"Food traceability is part of logistics management that capture, store, and transmit adequate information about a food, feed, food-producing animal or substance at all stages in the food supply chain so that the product can be checked for safety and quality control, traced upward, and tracked downward at any time required."* (Bosona and Gebresenbet 2013)

"The ability to track and trace the herbals, food and feed, foods derived from animals or plants, and materials contained in feeds with respect to production, process and distribution."[47]

> *"Traceability forms an apparatus in the Foucauldian sense, that is to say, a heterogeneous ensemble consisting of concepts, institutions, procedures, regulatory decisions, and scientific knowledge. It encompasses non-discursive elements (for example, the diverse techniques of identification: passwords, barcodes, RFID labels, electronic bracelets, DNA tests, retinal scanners, face recognition software, etc.), as well as discursive elements (for example, the imperative of security, along with the problematics met by the prevention of risk and the redefining of sanitary responsibility)."*[48]

Olsen and Borit (2013) clearly summarizes the traceability literature in their study, and their findings show that there exist contradictions to the term from academic papers. But they are agreed upon the importance of record keeping. The most prominent defect of definition in literature is expressed as they lack to define verb "trace" although many

[46] Codex Alimentarius Commission – Procedural Manual Twenty-Seventh. 2019. [Online]
[47] Veteriner Hizmetleri, Bitki Sağlığı, Gıda ve Yem Kanunu-Kanun No. 5996. Resmî Gazete, Kanun-Sayı: 27610; 2010. [Online]
[48] Chamayou, G., 2014. History and Philosophy of Traceability, Berlin: Germany.

defines traceability with this verb. Additionally, food traceability has significant place in many standards and literature as well. Cebeci and Kutlu (2009) categorizes traceability in six topics as traceability of (i) product, (ii) process, (iii) input, (iv) genetics, (v) disease and residue, and (vi) measure/quantification. Product traceability means the act of locating a product within supply chain physically to provide information for parties involved in chain. Process traceability aims at specifying the time, exposure, and practices of a product during production, storage, and distribution phases. Genetics traceability focuses on the genetic components of product and examines if product has genetically modified organisms (GMO) or materials. Input traceability keeps the record of by-products like water, chemicals, additives, seeds, etc. Disease and residue traceability keep the record of bacteria, viruses, etc. Measure/quantification traceability, lastly, determines the appropriateness of components and risk elements with respect to standards.

2.3.1 Traceability Systems and Models in General

Traceability system is "a series of mechanisms for traceability, by which "identification", "link", "records of information", "collection and storage of information", and "verification" are performed." Main components of traceability system are rules and procedures, documented procedures, organizations/systems, and process and management resources (personnel, financial resources, machinery equipment, software, technologies, and techniques), regulations and education / training.[49] It is also defined in ISO 22005[50] that a traceability system is "Totality of data and operations that is capable of maintaining desired information about a product and its components through all or part of its production and utilization chain."

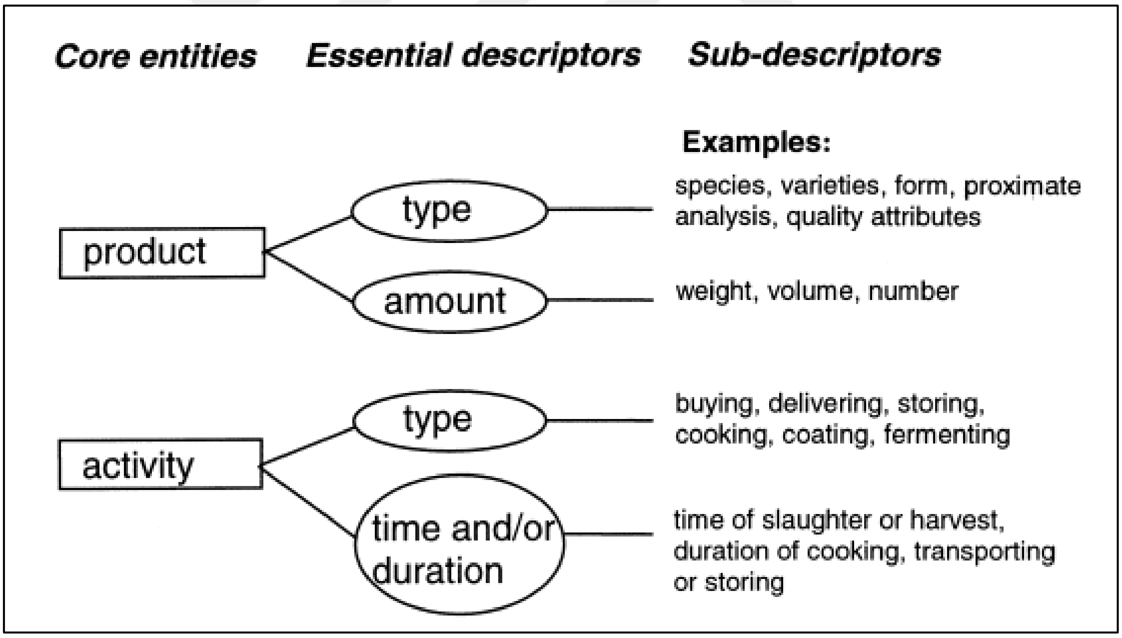
Basically, a traceability system is devoted to keep record of data as materials flow in supply chain from raw material supply to the end customer. Hence, the movement of materials is at the cornerstone of any traceability systems. It includes the path a material follows within supply chain. It simply considers the linkages between supply chain

[49] FMRIC, 2008. Handbook for introduction of food traceability systems (guidelines for food traceability). 2. ed. Tokyo: Food Marketing Research and Information Center.
[50] ISO 22005:2007(En) Traceability in the Feed and Food Chain — General Principles and Basic Requirements for System Design and Implementation. 2007. [Online]

participants. Therefore, it could be classified into two main categories as internal traceability where keeps the data of internal operations a product flows through supply chain within an organization, and external traceability keeping the records of information outside the organization, e.g., distribution, sales information[51]

Cebeci and Kutlu (2009) distinguish traceability systems as paper based and electronic based systems. Paper based systems are mostly used in small-scale organizations where information systems are not available. Electronic based systems, on the other hand, are the most used ones in today's world. Moe (1998) visualizes a structure for traceability system which includes product and activity as main components – Figure 2.10 as referenced. She also states that traceability system consists of two elements of which (i) product routes and (ii) extent of traceability represented as sub-descriptors in Figure 2.10.

Figure 2.10: Traceability system fundamentals



Resource: Moe, T., Perspectives on Traceability in Food Manufacture, 1998

Olsen and Borit (2013) list the features that a good traceability system includes as: (i) Traceable resource units (TRU) referring to the activity of grouping materials with same characteristics into units. (ii) Each unit should have identifiers or keys that are

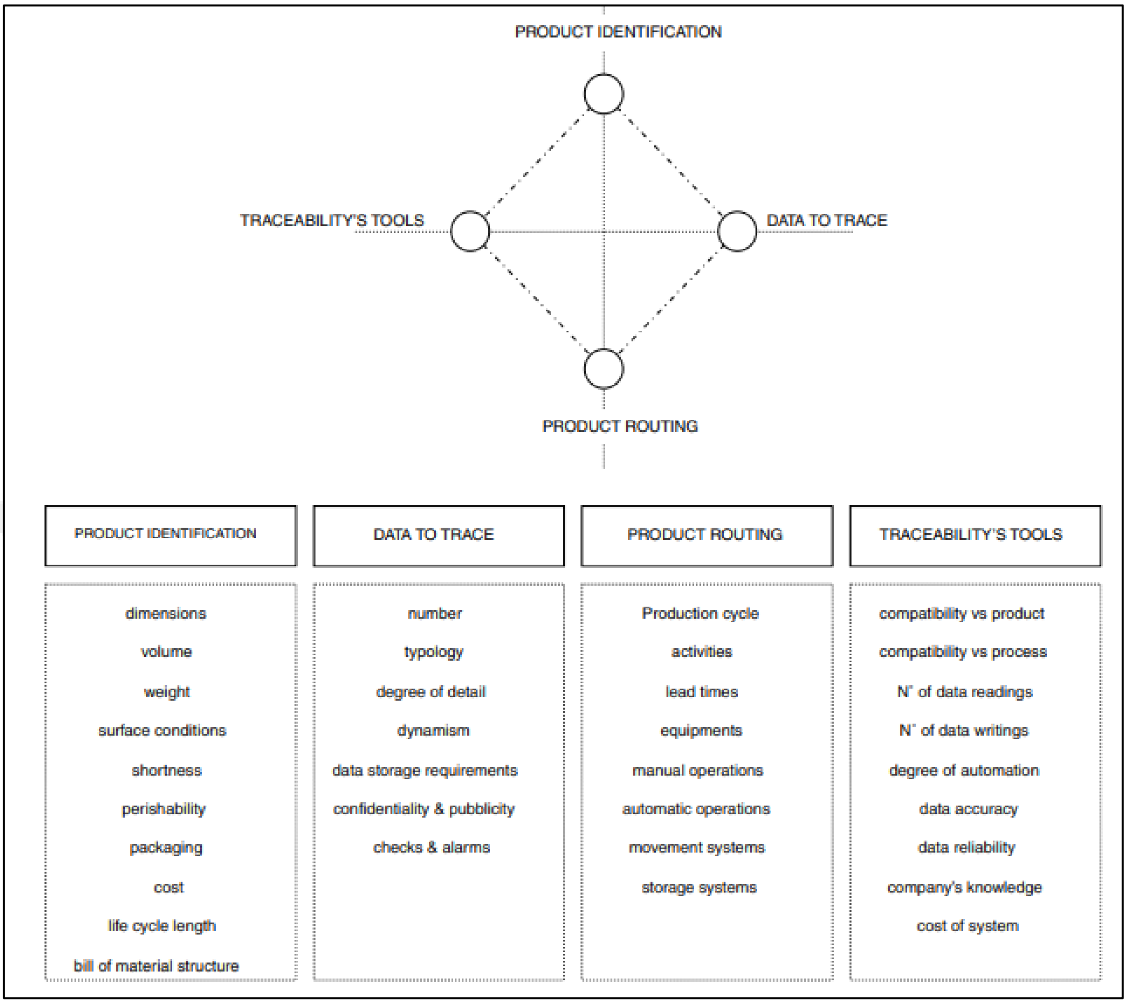
[51] International Trade Center, Traceability in Food and Agri-Products, 2020, [Online]

authenticated. (iii) Characteristics of product and processes should be transcribed and related to identifiers. (iv) Those characteristics should be accessible through a mechanism.

Bosona and Gebresenbet (2013) summarize technologies that organizations utilize in their traceability systems as product identification, quality and safety measurement, genetic analysis, environmental monitoring, geospatial data capturing, data exchange, and software. In addition to these technologies, Aung and Chang (2014), list Wireless Sensor Network (WSN) technology which enables gather of sensing data from physical or environmental conditions like temperature, humidity, etc. IoT is one of sensor technologies that makes it possible for commodities to communicate each other and exchange relative data needed.

Supply chain traceability is a mixture of complex information flows and needs integration between each flow. Parties involved in supply chain generate this information and should build integrity among themselves. Developing information technology is a catalyst for them to establish efficient models of traceability. Folinas et al. (2006) allocate information flows into two categories as one step up-one step down flow and aggregated information flow. The first category is suggested by EC Regulation, 178/2002 – especially for food chains. This model is consumer friendly as it records stage-wise information by following product up and down in the chain. It enables consumer to filter information regarding required information on quality and origin of products. The second model gives information all along the chain from farm to fork. There are more traceability models developed by researchers from different approaches to the traceability practices after Moe. Regattieri et al. (2007) based on Moe's model for fundamentals of traceability – see Figure 2.11. Their model distinguishes four main components as product identification, data to trace, tools, and routes. Each activity has different factors of information as well. They apply this model on a cheese manufacturer and have resulting points that use of RFID system enable cheese manufacturers to track reliable product information and speed up the re-call processes, customers are able to see product history of cheese from website, and 0.5 percent economic impact on final price.

Figure 2.11: Product traceability framework by Regattieri et al.



Resource: Regattieri, et. al., Traceability of Food Products: General Framework and Experimental Evidence, 2007

van Dorp (2003) has built a data model to display the relationship of lots and batches, operations of production, related variables and values, control, and finally capacity units. It enables the trace of activity generation. Bechini et al. (2008), in addition to previous models, offers a traceability model through Unified Modeling Language (UML), a language to specify, visualize, construct, and document the entities of an information system. He distinguishes two categories as traceability and quality where traceability entities cover required components to track a product back and forth on the chain, and quality entities evaluate traceability entities. The model identifies classes and patterns for express lot activity on supply chain. Khabbazi et al. (2010), provide a model by integrating previous models with adding two more relationship entities between production - operation and purchase - quality. Their model offers ability to track all data from purchase order to end product within chain. They support that the model implementation would make it easier to keep and evaluate divergences.

2.3.2 Traceability in Food Chains

Food sector has an important effect on our lives. Food traceability is on demand after major outbreaks in food chains affecting world health. People are more insistent on healthier, quality, and transparent products as they lose trust against food sector players after food caused illnesses. Consumers are becoming more conscious and they want to know the history of food they put on their table for themselves and for their families. Producers are also becoming more careful in a global world where bad news spread fast than good. Any problem in their chain affects the producers and brands at huge costs as many operate international-wide. Quality of raw material to the by-products are very important for the final product to be marketable. Also, detecting problems, acquiring certificates, and successful audit processes enable enterprises to be more competitive and be among top players today. Development of traceability systems, therefore, become a mandatory issue for any supply chains to keep on the market and achieve their objectives. Traceability is the activity of examining where food comes (one step down) and where good goes (one step up). It is a way of developing mechanism of warning for preventing problems and risks in food supply. It also eases the process of reverse logistics if recall action is necessary. Each food entity is monitored through TRUs along the food chain (Espiñeira and Santaclara 2016).

Before obtaining a food traceability system, it is important to have a good plan and set clear objectives that are achievable within the availability of resources and technology. Below are some examples that can be set for a food traceability system[52]: (i) Sustainable food safety to easily detect the problems affecting human health and overcome unexpected risks of recalls. (ii) Obtaining reliable information with respect to food history on the chain to enable transparency, ease of verification, and trust from external parties like government, customer, and other legal authorities. (iii) Efficiency gain through a good management of inventory, quality, and communication.

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[52] FMRIC, 2008. Handbook for introduction of food traceability systems (guidelines for food traceability). 2. ed. Tokyo: Food Marketing Research and Information Center.

In consideration of the possible objectives listed above, we may predict the factors affecting the demand for food traceability systems as safety and quality concerns, regulatory forces, social impact, economic concerns, and technological developments. Governments are putting mandatory duties on food producers or sellers to have specific requirements. EU for example requiring compulsory act and data from food suppliers by the force of General Food Law (GFL). Food safety and quality is being questioned as well by consumers and legislative bodies after food crises, e.g., salmonella outbreak in cut fruit, E. coli infection from romaine lettuce, salmonella infection in frozen raw tuna is just a few from 2019.[53] Unsecured food products are also damaging the foreign trade if the standards are not fulfilled by exporting countries. Increase in income has affected consumption behavior of societies. They have become more demanding on safe, fresh, nutritious food which forced food chains to provide more information on the food they supply to the market. From economic and technological perspective, building a good traceability system is hard and complex as it needs lots of investment and effort. However, the advantages in investing traceability systems are non-negligible in a sense that a successful food traceability system paves the way to competitiveness in the market, support from government and consumers, and traceability in international markets. Advanced technologies like IoT, sensor technologies, blockchain, etc. motivate the food chains to develop traceability systems for leveraging cost-efficiency in the market (Bosona and Gebresenbet 2013).

2.3.3 Issues and Regulations

Major issues concerning food chain traceability can be classified under three categories of technical, managerial, and environmental (Aung and Chang 2014). This classification gives us a broad view on the requirements for a successful and applicable food chain traceability mechanism in real case practices. Companies should take these categories into careful consideration and should develop a good understanding and knowledge of each element to build strong traceability systems.

[53] Centers for Disease Control and Prevention, List of Selected Multistate Foodborne Outbreak Investigations, 2020, [Online]

Although technical issues are under the initiative of food companies, some managerial and environmental issues might be subject to laws and regulations in different regions. Europe as the active player on legislative actions, put regulations into practice through European Food Safety Authority (EFSA). EFSA forces food suppliers to keep record of information regarding supply and sales processes. The Regulation (EU) No 1169/2011, reviewed in 2015, clearly states the responsibilities of food suppliers against consumers in term of providing reliable information through labels of foodstuffs. One of the key points from legislation transcribes the responsibility of manufacturer to provide necessary and accurate information of name, ingredients, quantity, expire date, nutrition, etc.[54] Very first implementations of food legislations go back to 1986 when UN General Assembly put the guidelines for consumer protection into force. After that, The Codex Alimentarius prescribed by FAO and WHO was developed for providing detailed perspective on food safety and quality issues. USA also gives brief guidelines for food industry on how to achieve traceability goals in food chains by publishing Traceability for Food Marketing and Food Safety: What is the Next Step. General Food Law put into force by EU in 2002 for specifying on traceability requirements across European countries (Regattieri et al. 2007).

ISO standards (ISO 9001:2000 and ISO22000:2005) are international standards focusing on quality management and food safety management through traceability assurance. One of the principles offered within ISO22000 is HACCP framework for hazardous material traceability.[55] In Turkey, various regulations are put into force in line with EU integration. In 2002, labeling and identification of food materials is published within The Notification of Turkish Food Codex on General Labeling and Nutritional Labeling Rules (Türk Gıda Kodeksi Yönetmeliği Gıda Maddelerinin Genel Etiketleme ve Beslenme Yönünden Etiketleme Kuralları Tebliği). In 2004, to fill the gaps in previous Codex, establishment of traceability systems in food sully chains is made compulsory. In 2008 and 2010, traceability concept has gained a more comprehensive explanation. Currently, food chain

[54] Regulation (EU) No 1169/2011, 2015. Labelling of foodstuffs. [Online]
[55] FMRIC, 2008. Handbook for introduction of food traceability systems (guidelines for food traceability). 2. ed. Tokyo: Food Marketing Research and Information Center.

traceability is regulated under The Veterinary Services, Plant Health, Food and Feed Law No: 5996 issued by Ministry of Agriculture and Forestry.[56]

2.3.4 Benefits of Food Traceability

Forced by the regulations and consumers, establishment of a good traceability system has benefits to the companies in different ways. Traceability systems enable companies to fulfill orders on time and accurately, to lower down inventory cost, to decrease information asymmetry, to answer unforeseen events and problems through supply chain, to satisfy customers and stakeholders involved in the chain, and finally better management of organizations (Öztürk 2010). Moe (1998), one of the most cited work in traceability topic, lists the benefits obtained from traceability as (i) better management and control over processes and product quality, (ii) finding solutions to the problems faster, (iii) raw material optimization, (iv) enhanced audit processes, (v) better track of raw material quality, and (vi) fulfilling the standards and requirements of legislations. Cebeci (2006) also provides a list of benefits that could be obtained by implementing traceability system in supply chain. Major benefits a traceability system can offer are obtaining statistical data of processes – leading to improvement of quality management systems, diminishing the risks and costs by recall products, better track of defective products in case of recalls – enabling to protect brand image, fighting against fraud and counterfeit products that may affect societal health, gaining competitive advantage in the market by building trust between stakeholders from supplier to the end customer, and effective management of certifications and accreditations in accordance with the regulations. Bosona and Gebresenbet (2013) list their findings on food chain traceability benefits as consumer satisfaction, crisis management, better management of chain, competitiveness, sustainability, and technological advancement.

2.3.5 Challenges in Food Traceability

Yet, food chain traceability is not an easy practice at all. Supply chain's complex structure makes it harder to implement a fully successful traceability system. Different

[56] 5996 Sayılı Kanun. 2020. [Online]

characteristics of food products sophisticates the products flow traceability, e.g., bulk vs. packaged. Prevention of cross-contamination between batches and lots gets harder due to the nature of food supply chains. Some food products contain many different ingredients and by-products. Tracking the data regarding these ingredients is not easy through all processes. Multi-stakeholder structure of food supply chains makes it more difficult to track and keep all information interchanged among those parties internally and externally. Also, not all foods are long lasting, fresh foods or dairy foods, for example, should be tracked accurately regarding the conditions they get exposed to during processes of supply chain to offer good quality products to the market (Espiñeira and Santaclara 2016). Çetin (2014) in her study, finds out the challenges regarding implementation of traceability systems as large investment cost, prioritizing other practices, lack of expertise and information on topic, lack of knowledge on regulations, and perceiving the traceability as an unnecessary practice. Bosona and Gebresenbet (2013) list barriers that food supply chains face when that try to integrate traceability system in their organizations as resource, information, standardization, capacity, and awareness limitations.

Food chain traceability has gained a significant place in literature as concerns on public health grows after serious food-borne outbreaks. Scandals in food sector have pushed the limits of consumers as many killed by contaminated food. Olsen and Borit (2013), in their study, tried to answer what traceability means by reviewing the studies and definitions of various institutions. McEntire et al. (2010), on the other hand, proposed breadth (quantity of information), depth (flow along the chain), precision (accuracy of information), and access (speed of information exchange) features to the food supply chain traceability as a reference point. Various researchers have proposed different traceability models and frameworks many of which are applied in the food industry. Bougdira et al. (2019) propose a knowledge-based conceptual model while Sanchez et al. (2015) propose a theoretical model for SMEs to enable more efficient and reactive operation management. Regattieri et al. (2007) approach to the traceability from a different perspective where they describe four features; product identification, trace of data, routing, and tools utilized. Storoy et al. (2013) build the TraceFood Framework while Pizzuti and Mirabelli (2015) propose the Global Track and Trace System which has a broader approach to the industry. Salampasis et al. (2012) propose a semantic framework called TraceAll for food chain traceability found out to be cost effective and interoperable for food supply chains. Shanahan et al. (2009) offer a model using RFID technology for beef traceability. Folinas et al. (2006) proposed a model of data management for fresh foods using web-based technologies of Physical Markup Language (PML) and eXtensible Markup Language (XML). Thakur and Hurburgh (2009) build a framework on XML as well to keep track of grain supply data. Ruiz-Garcia et al. (2010) develop a framework for tracking agri-food chain and offer utilization of web-based system to enable exchange and record of data. Alfaro and Rabade (2009) have studied a case in Spain for vegetable sector presenting that computer-based traceability system may improve supply chain processes. Mattoli et al. (2010) and Li et al. (2010) offer a traceability system through digital tags in different products in food industry. Many researchers have been examining the effective use of RFID technology for building smart supply chains where full traceability is possible through the chains (Wang et al. 2010; Abad et al. 2009; Zhang et al. 2009; Hsu et al. 2008; Mousavi et al. 2002)

Blockchain is relatively new technology to the existing traceability technologies and is getting attention from science and industrial world each day because it is offering a decentralized network where the data is immutable and traceable to all stakeholders within the scope of applied blockchain type. If we summarize the studies conducted in literature so far, we can group papers according to the food type on which they develop blockchain solution or framework for the sector. There are studies examining and building blockchain solution for agri-food goods (cereals, olive oil, etc.) by Feng et al. (2020), Guido et al. (2020), Kamble et al. (2020), Salah et al. (2019), Scuderi et al. (2019), Surasak et al. (2019), Xie and He (2019), Wang and Liu (2019), Casado-Vara et al. (2018), Hong et al. (2018), Li and Wang (2018), and Lin et al. (2018) for meat by Meidayanti et al. (2018), for eggs by Bumblauskas et al. (2020), for dairy products by Casino et al. (2020). Dasaklis and Casino (2019) and Kim et al. (2018) studied blockchain technology with respect to tokenization of supply chain processes. Behnke and Janssen (2020) examined legal frameworks relating to the blockchain technology practices in food supply. Also, some researchers proposed blockchain solutions utilizing supplementary technologies like IoT Pal and Kant (2019), Caro et al. (2018), and Tian (2017). Bettin-

Diaz et al. (2018), besides, focus on the blockchain technology from customer perspective where they demand more knowledge on the product origins they buy. Casino et al. (2020) and (2019) tried to build a traceability framework for food supply chain utilizing smart contracts. Galvez et al. (2018) published a study focusing on challenges of applying blockchain in food supply chains while Chen et al. (2020) focused on benefits in addition to challenges from a thematic perspective. Tan et al. (2020), propose a different model to the existing literature from perspective of halal food supply through blockchain. Tse et al. (2017) propose and approach for information flow where blockchain would enable secure exchange of information in comparison to traditional supply chain practices. Kayikci et al. (2020), additionally, propose a model within people, process, and technology (PPT) framework to examine challenges and opportunities of this technology for future cases. Kittipanya-nham and Tan (2019) also focus on challenges and opportunities in their work by examining three different companies in food sector. Rogerson and Parry (2020) pursue case study approach and propose implications for theory and practice in food supply. Duan et al. (2020) is the most recent review paper exhibiting a summary of papers and giving significant insights on blockchain adoption in food supply chain in terms of benefits and challenges the literature and case studies have deduced up to today.

Literature findings support that blockchain technology is a milestone for food chain traceability. Galvez et al. (2018) support the benefit of technology that it would prevent fraud and counterfeit products while it also provides efficient, cost-effective, fast, trustworthy environment in food chains. Caro et al. (2018) with the model implementation on Hyperledger and Ethereum provided important results expressing that blockchain is an important tool to increase speed in audit processes. Walmart and IBM case on mangoes has shown that speed of tracking mango movement decreased to almost 2 seconds from 7 days with blockchain implementation (Yiannas 2018). Another pilot study in agri-food sector also supports the outcomes of Walmart-IBM case[57] Blockchain technology is beneficial in terms of decreasing information asymmetry and providing decentralized network of stakeholders which results in elimination of intermediaries and access to

[57] CBH Group and AgriDigital, 2017. Pilot Report: Solving for Supply Chain Inefficiencies and Risks with Blockchain in Agriculture, Australia: AgriDigital.

information directly (Queiroz et al. 2019; Tian 2017). Tian (2017) also shows that immutable data feature of blockchain technology enables trust, reliability, automation, and ease of verification within food supply chains. Another case from Walmart with Tsinghua University for tracking pork provides significance since it exemplifies the benefits of technology in practice from perspectives of information reliability and trust-building (Yiannas 2018). IoT is one of the important technological developments for supply chain efficiency as it provides incredible data exchange between materials. However, it has downfalls since the data it collects is extremely huge and complicated. It is also open to attacks from outside where the reliability of data obtained with IoT devices are questionable. Therefore, many researchers suggest blockchain and IoT integration in supply chain as a combined model. Blockchain can provide security for the data obtained through IoT devices (Rejeb et al. 2019; Galvez et al. 2018; Leong et al. 2018; Lin et al. 2018; Rejeb 2018; Tian 2017; Tian 2016). Blockchain technology provides huge potential for more sustainable food chains by improving recall efficiency and better waste management as well (Zhao et al. 2019; Yiannas 2018).

Although blockchain technology has very beneficial promises for food supply chains, it does not come with all benefits. It has downsides too. The technology is relatively new and developing each day. As new pilot studies and research have been conducted, prominent challenges are revealed as well. One of the challenges in front of this promising technology is the lack of understanding the basics and working structure of blockchain technology itself. It is a complicated technology advanced through different technologies like cryptology, smart contracts, and other software requirements. Therefore, companies need to understand their needs and then should decide if they need blockchain or not. A detailed profit-loss analysis before implementing a blockchain solution to the existing practices is compulsory for all supply chain actors (Kamilaris et al. 2019; Queiroz et al. 2019; Zhao et al. 2019; Galvez et al. 2018; Leong et al. 2018; Verhoeven et al. 2018; Hackius and Petersen 2017). Blockchain has issues of scalability especially in public blockchains where security and immutability are higher. The most prominent example of scalability challenge is Ethereum transaction capacity against Visa.[58] Supply chains include large number of stakeholders and generate vast amount of data in each step.

[58] CoinDesk, What is Ethereum?, 2020, [Online]

Hence, correct assessment of scalability is important for supply chain if blockchain implementation is considered by companies (Pearson et al. 2019; Leong et al. 2018). Other concern for blockchain implementation is the accuracy and security of raw data input placed on the blockchain ledger (Galvez et al. 2018; Kshetri 2018; Leong et al. 2018; Lin et al. 2017; Tian 2017).

Multi-stakeholder structure of supply chains makes it harder for involving every one of them in the blockchain-based system. Especially, small companies find it difficult to bear investment cost of building or adopting a blockchain solution. It is important that all stakeholders are involved in the blockchain system to take full benefit of the technology. Otherwise, it does not provide efficient results (Kamilaris et al. 2019; Pearson et al. 2019; Leong et al. 2018; Perboli et al. 2018). Perboli et al. (2018) highlight this problem in their research by developing a model on Hyperledger Fabric where small companies may benefit from as well. Blockchain technology also lack regulative framework and it affects adoption of technology in food supply chain since it is important to fulfill certain conditions within regulations and laws summarized in 2.3.3. Although many countries are working on building legislative framework for blockchain adoption, there is still no strict and detailed written rules put into force (Kamilaris et al. 2019; Pearson et al. 2019; Leong et al. 2018).

3. A BLOCKCHAIN BASED TRACEABILITY MODEL DEVELOPMENT FOR DAIRY FOODS SECTOR

In this section, we provide the methodology and steps of building our model. We start with analyzing the dairy food sector in a broad sense and then, continue with Kashar cheese supply chain system explanation. After, we explain the components of our blockchain traceability model with regards to supply chain members and product involved in each process. Then, a supply chain flow scenario where cheese is manufactured is given with proposed blockchain model application.

3.1 METHODOLOGY

Aim of this study is to develop a conceptual framework of blockchain traceability mechanism for food supply chains. Food sector is essential for sustainability of societal health as foodborne diseases affect human health deadly. Traceability of food supply chains is important eliminator for decreasing deadly outcomes of foodborne diseases since it enables trustworthy, secured, and reliable information on the food history along the chain. Additionally, the quality and hygiene requirements are easily controlled by producer, auditors, and consumers if a proper traceability system is adopted. Cheese is one of the indispensable products for our body health as it contains high amount of protein and calcium nutrition. Therefore, cheese food supply chain is chosen to develop the conceptual traceability model on blockchain. Model development begins with the analysis of supply chain flow for a Kashar cheese manufacturing company. The generic supply chain diagram for the Kashar cheese company's supply chain is deduced and used.[59] The blockchain traceability model of this thesis is built on that diagram (see Figure 3.1) (Ediz 2014). After examining the supply chain flow of Kashar cheese, following steps are performed to develop a sound blockchain traceability model from a conceptual approach. The very first step of developing the blockchain model is to determine

[59] Due to the pandemic conditions, site visit is not been able to be performed. Instead, supply chain flow diagram from a published thesis on Kashar cheese traceability is utilized. The diagram is accepted as valid for today after recent studies and other real-world cases from company reports are examined and compared to the diagram.

requirements and decide on what platform to build blockchain traceability solution. From the literature, we may list the requirements as security and authenticity of information, traceability of information (materials, transactions, authorities, organizations, distribution) generated at all stages, access of information through a synchronized network, access permissions to the specific information by specific entities, and automated transactions via smart contracts. Upon these requirements, an appropriate blockchain mechanism (see 2.1.5 for more information) is chosen for the model to be built on. After a detailed comparison between available blockchain solution frameworks, Hyperledger seems to be the best fit with the required features (see Table 3.1).

The second step, after deciding on the blockchain platform and requirement analysis, is to determine the actors involved in the processes. This is needed to properly define the roles and abilities of actors that will be integrated on the platform. The third step is determining the data entries required and generated through the chain. This starts with the data generated by suppliers when the manufacturer procures the raw materials put into the production. Data requirement determination is formulated with reference to the Critical Tracking Events (CTEs) and Key Data Elements (KDEs) framework updated by Institute of Food Technologists (IFT). Please see Appendix 1 for more information. After we specified the model components, it is time to set up for conceptual design where we explain design elements and relationship between elements. Design elements are grouped into three categories as actors, assets, transactions, and inquiries. Actors are defined under Heading 3.2.1. Next step is to determine the permissions to satisfy security and access requirements of the model. It basically defines who can do and see what on the platform. It also specifies the management of data pertained to the actors, transactions, and assets.

3.1.1 Sector Information

Dairy foods industry is an important component within food supply chains since it carries significant impact on people in terms of nutritious contributions to our body. It is an important source of protein and calcium which are vital elements to sustain body health. Global milk production in 2019 was 852 million tons. Global output exhibits a 1.4 percent increase from 2018 to 2019. Major players in the sector are India, Pakistan, Brazil, the

EU, Russia, USA, Australia, Turkey, Colombia, Argentina, and Ukraine. Asia is the largest producer in the market with 360 million tons in 2019. Europe takes the second place with 226 million tons. Russa is investing on modern farms to increase quality output. USA is at the third place in production with 108.6 million tons, which exhibit decline compared to 2018. Africa is struggling with challenges of dry weather conditions affecting pastures and high cost of transportation and animal feed. Overall trade of dairy foods in 2019 has an increasing pattern for the last three years. Exports increase of 1 percent is observed in 2019 equivalent of 76.7 million tons in quantity. Europe is the largest exporter of dairy food and Asia is the largest importer with almost 46 million tons. New Zealand, the European Union, Turkey, Egypt, and Belarus are the major suppliers of increasing demand in 2019. Major components of dairy foods are butter, cheese, skimmed milk powder (SMP), whole milk powder (WMP), yoghurt, etc.[60] Global market share of dairy products measured as 458.1 billion USD in 2020 and expected to grow up to 587.5 billion USD by 2027.[61] In 2019, total revenue of food sector globally was 6,953.9 USD. Share of dairy products and eggs compounded 11 percent by creating 743.1 billion USD revenue in 2019.[62] Turkey's dairy food production is measured as approximately 380 thousand tons in September 2020 and 3 million tons for 2020. Among products, milk is the largest share and followed by yoghurt and cheese.[63]

Deloitte report on dairy food supply chain has prominent implications for producers. Changing demand towards healthy diet has made dairy foods important part of consumption patterns. Major challenges in dairy food sector are listed as volatility of prices, consumer behavior, demand of safe, secure, and quality products, sustainability concerns, and adaptation process of new technologies. Report results show that there is a growing lack of trust against brands as customer demand more information for specific ingredients, how the product was made, where it was made, corporate values of the manufacturer and retailer, etc.[64] Increasing notifications on dairy product related outbreaks are very important to take traceability issues during supply chain into

[60] FAO, 2020. Dairy Market Review, s.l.: Food and Agriculture Organization of the United Nations.
[61] Research and Markets, 2020. Dairy Products - Global Market Trajectory & Analytics, s.l.: Research and Markets.
[62] Frimpong, J., 2020. Dairy Products & Eggs Report 2020, s.l.: Statista.
[63] TUIK, Süt ve Süt Ürünleri Üretimi - Eylül 2020, 2020, [Online]
[64] McMahon, M., 2017. Global Dairy Sector – Trends and Opportunities, Delloite: The Netherlands.

consideration. Any contamination by pathogenic micro-organisms (e.g., Salmonella spp., Staphylococcus spp., Listeria monocytogenes, Escherichia coli O157:H7), spoilage micro-organisms (e.g., molds) and hygiene indicator microorganisms (e.g., coliforms), or chemical substances (e.g., antibiotics) has vital effects on population health.

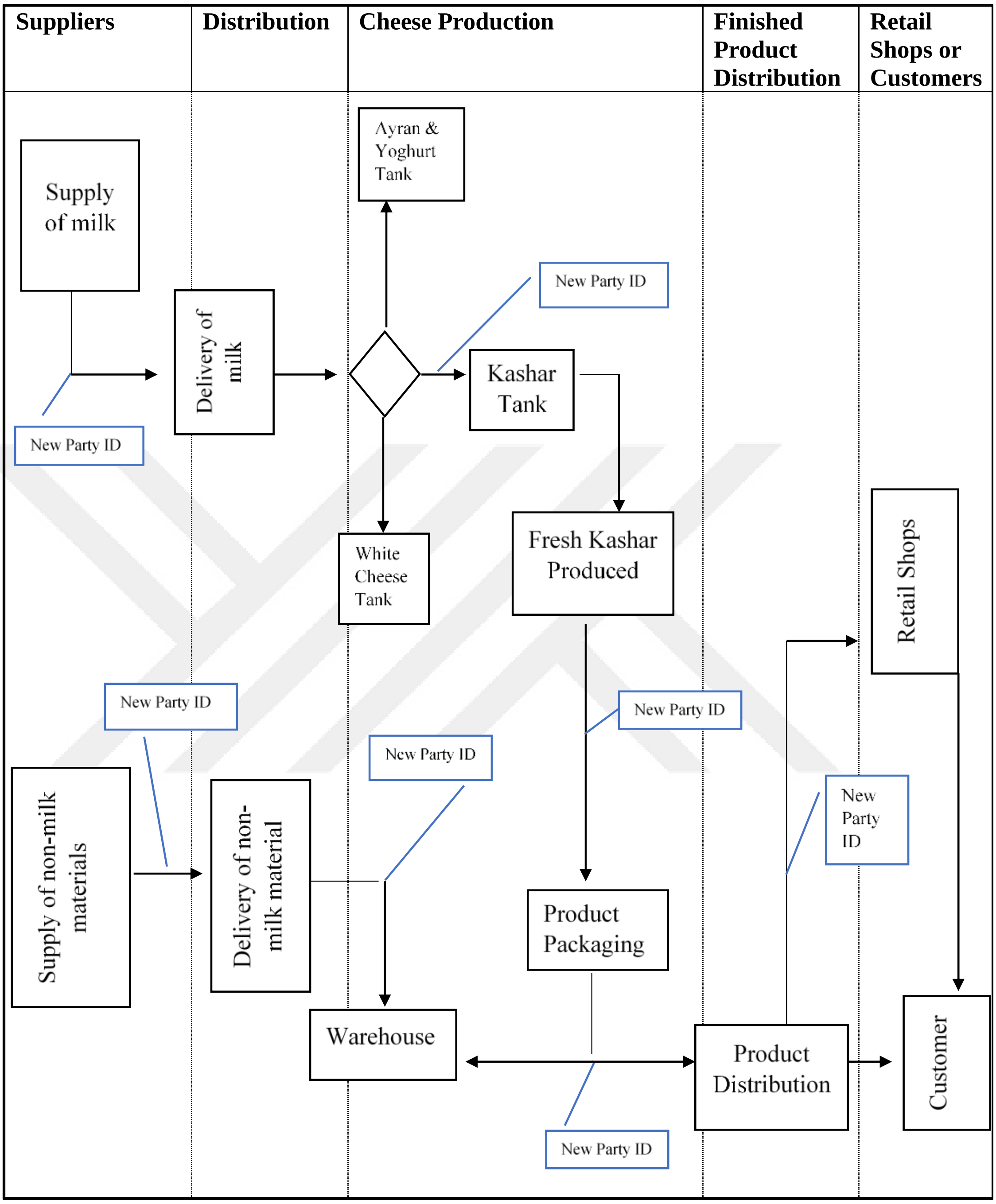
3.2 KASHAR CHEESE SUPPLY CHAIN FLOW

This thesis suggests a blockchain traceability model built on a generic Kashar cheese supply chain system of an existing company. The company lacks efficiency in their system as they did not have a proper traceability mechanism in their processes although they used an Enterprise Resource Planning (ERP) software (Ediz 2014). The company had a capacity of 200 tons/day production in milk processing for the segments of yoghurt, ayran, white cheese, Kashar cheese, and other local cheese types at the time of study conducted. They had a 9000 m2 closed area where the operations took place. With 200 employees, they mostly sell their products through franchises in different cities. They have developed a software to track all the way from procurement to the distribution. Software language they used is visual basics and sp.net, and data recoding is done by SQL server database.

Kashar cheese production in the aforesaid company is divided into two sections: milk flow (major input) and other supplements used for production. Milk after procurement from suppliers is first checked for the content suitability, second passed through pasteurization, third transferred to the Kashar cheese tanks, and then sent to one of the boilers within specific time frames. Along with this process, other ingredients, and packaging materials to be used in Kashar cheese are brought together with milk and semi-products obtained from milk at different stages. The first conversion takes place in boiler and processed together with other ingredients through heating and mixing. After the milk is fermented at a specific consistency level, it is transferred to the drum filter and waited until the whey within it completely filtered. Semi-product obtained from filtering process is transferred to the curding counters. The mixing of semi-product is continued on these counters. After curding, the semi-product is transferred to the wet boiling counter. During wet boiling, semi-product is pasteurized and cleared of microbes under the condition of

85°C heath and cooling process. After wet boiling, obtained product is molded to give a certain shape and then sent to the waiting rooms to wait for one day long. After waited one day, the product is sent to packaging line to be wrapped with foil and labelled. After labelling, it becomes a finished product to be stored in distribution warehouse. From warehouses, the finished products are distributed to the franchises or retailer to be sold to the end customers. Figure 3.1 below is the visualization of Kashar cheese supply chain flow formulated in accordance with the processes of the company. The chain includes all the processes from supplier to the end customer. During the processes, new party ID is given to the products to ease the track on the system as a whole. IDs are the representatives of real products on the system. Conceptual blockchain traceability model is developed according to information given on the figure.

Figure 3.1: Kashar cheese supply chain flow diagram



3.2.1 Proposed Conceptual Blockchain Traceability Model Components for Kashar Cheese Manufacturing Flow

Aim of this study is to develop a conceptual framework of an alternative blockchain traceability mechanism for the visualized Kashar cheese supply chain flow. The very first step of developing a blockchain model is to determine requirements and decide on what platform to build blockchain traceability solution. From the literature, we may list the requirements as security and authenticity of information, traceability of information (materials, transactions, authorities, organizations, distribution) generated at all stages, access of information through a synchronized network, access permissions to the specific information by specific entities, and automated transactions via smart contracts. Upon these requirements, an appropriate blockchain mechanism (see 2.1.5 for more information). After a detailed comparison between available blockchain solution frameworks, Hyperledger seems to be the best fit with the required features (see Table 3.1) for the time this thesis is completed.

However, it is a must to note that blockchain technology is developing and new platforms with enhanced features are being offered. Especially, Ethereum 2.0 is trying to eliminate scalability issue of current version in very near future. Although Hyperledger is famous among corporate giants, it has limitations to the smart contract enhancement. Therefore, there is room for Hyperledger platform to adapt to the necessities of complex supply chain systems. It is a very competitive environment and as new platforms present integrated features, Hyperledger can lose its reputation among business networks.

Table 3.1: Comparison between Ethereum, Hyperledger, Corda blockchain platforms

Features	**Ethereum**	**Hyperledger**	**Corda**
Platform	Generic	Modular	Specialized for financial industry
Usage	Popular for B2C	Popular for B2B and enterprise use	Popular for finance enterprises
Governance	Ethereum Developers	Linux Foundation	R3Company
Operation Type	Permissionless, public or private	Permissioned, private	Permissioned, private
Consensus	Updated PoW with staking	Broad understanding of consensus at transactional level and not all nodes are needed for decision making	Specific understanding at transactional level and only involved parties needed for decision making
Smart Contracts	Solidity	Golang (Go Java)	Kotlin, Java, or legal purpose contract code
Currency	Ether, tokens via smart contracts	No currency but can be included via chain code	No currency

Resources: Comparison of Ethereum, Hyperledger Fabric and Corda Report, 2017 and Hyperledger vs Corda R3 vs Ethereum: The Ultimate Guide, 2018

The second step, after deciding on the blockchain platform and requirement analysis, is to determine the actors involved in the processes. This is needed to properly define the roles and abilities of actors that will be integrated on the platform. Actors involved in Kashar cheese manufacturing flow are listed as:

i. Supplier Level
   a. Suppliers of milk
   b. Suppliers of other ingredients
ii. Manufacturer Level
   a. Employees
   b. Managers
   c. Distributors
   d. Retailers
iii. External Level
   a. Auditors
   b. Certifying Authorities
iv. End Customers

Table 3.2: Roles pertained to the actors

Actors	Roles
Suppliers	Supply of raw material Supply of related information to the raw material Supply of transactional data for the smart contract
Manufacturer	Record of procured raw material Content check for quality of raw material Transfer of materials within chain Provide relative information regarding manufacturing processes at each phase Update changes to the raw material, semi-product, or inventory. Maintenance of the platform and the manufacturing machineries Preparation of reports, analysis, and other related documents regarding the processes and quality of products Movement of goods from raw material to the end customers Proper storage of materials, semi-products, and finished products Record of data regarding assets
External Bodies	To check the reports, information, and related data to provide reliable certification

Table 3.3: Activities pertained to the actors on the platform

Activities at Supplier and Manufacturer Levels on the Platform
Putting actions forward Creating, editing, and deleting assets representing materials, products, people, and other actors on the platform Reading information regarding materials, products, actors, transactions on permission Writing and deploying smart contract agreements on the platform Tracking all the transaction history regarding a product flows through in the chain Tracking of possessions Generating shipments and creating connection within contract Tracking all the transaction and information history of shipments created Tracking the user information within shipments Tracking asset information within shipments Tracking status, location, and content of shipments Generating information of damage if occurs to Updating all the information a shipment generates Creating, editing, and deleting IDs Holding crypto or token representing fiat money to initialize transactions
Activities at External Levels on the Platform
Requesting and tracking of information regarding materials, products, and processes along the chain Requesting and tracking of information regarding actors and assets created on the platform

The third step is determining the data entries required and generated through the chain. This starts with the data generated by suppliers when the manufacturer procures the raw materials put into the production. Data requirement determination is formulated with reference to the Critical Tracking Events (CTEs) and Key Data Elements (KDEs) framework updated by Institute of Food Technologists (IFT). Please see Appendix 1 for more information. Relative data generated by different actors on the platform are:

i. Data generated by suppliers

a. Supplier information (company ID, location, brief history, contact information, production capacity, certifications, employee profile, etc.)

b. Information regarding milk as major raw material (Milking time, employees information responsible from milking, location of milking, animal ID, milking cup ID, milk quantity, milk contents – pH, fat, water, intensity, heath, dry material, antibiotic data, etc.-, party ID of milk, and movement of party ID)

c. Information regarding other ingredients

d. Information regarding supplementary raw material (packaging material ID, quantity, quality, movement of material, etc.)

ii. Data generated at the manufacturing level

a. Procurement of raw material (supplier information, raw material information – party ID, quantity, quality, location, movement, responsible employee -, time stamp)

b. Content quality check (content measures – pH, fat, water, antibiotic levels -, time stamp of quality check, suitability report)

c. Raw material movement (record and tracking of party ID of collected milk through transfer to the tanks, mixing, boiling, drum filter, curding, wet boiling, molding, packaging, storing, and finally distribution processes, reports, extra notes, certificates for production, etc.)

d. Raw material location (e.g., in tank no 1, in boiling room 1, etc.)

e. Employee ID (name, contact info, position, assigned roles, access permissions, etc.)

f. Machinery ID (description, functionality, time bought, maintenance requirements, etc.)

g. Process descriptions (each process Kashar cheese pass through should be described in detail to provide automation through smart contracts)

h. Relationships between processes (order of flows should be defined precisely)

i. Distributor ID (company ID, location, contact, brief information, capacity, asset requirements – e.g., cold chain transportation -, certificates, etc.)

j. Inventory information (record of items, semi-products, finished products, etc. by party IDs to enable proper track of inventory)
k. Actor related information (user data, category, access date, access keys, permissions, etc.)
l. Retailer ID (company ID, location, contact, brief information, demand data, demand fulfillment, etc.)
m. Semi-product information (time stamp, quantity, quality, whey produced, waste produced, location, movement, etc.)
n. Finished product information (time stamp, quality, shape, quantity, packaging, labeling, storage, distribution, etc.)

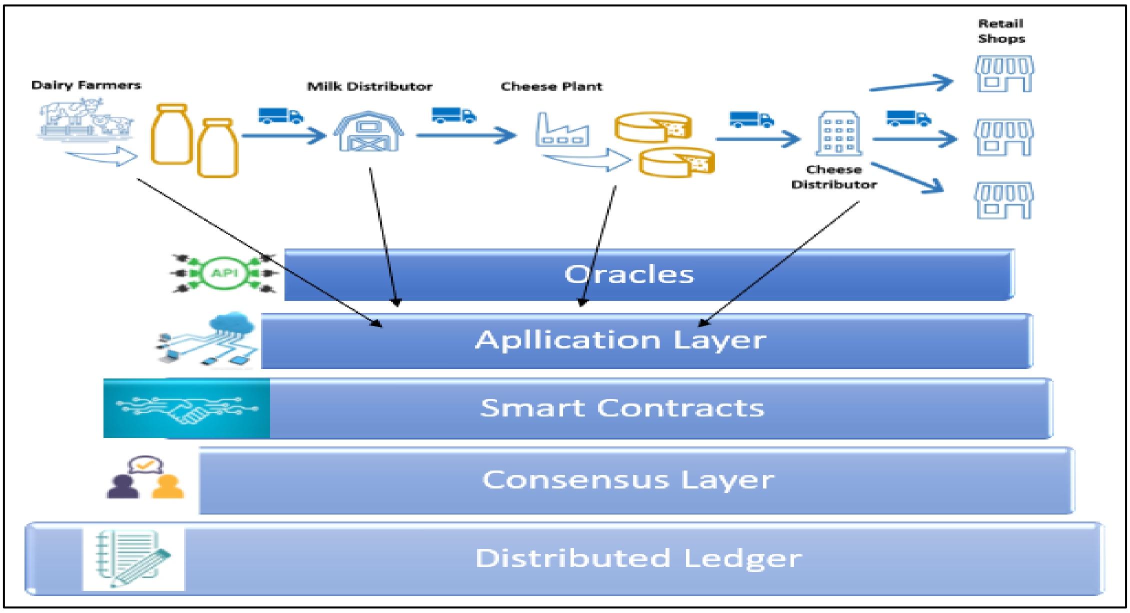
iii. Data generated at the regulatory level
   a. Audit reports regarding processes, employees, financial situation, etc.
   b. Certifications on finished product quality and marketability
   c. Labeling suitability to the regulations

iv. Data generated at the end customer level
   a. Customers should be able to reach this information through a QR code attached on the package: Product origin, company IDs, supplier information, production process, certifications, distribution information, nutritional data, ingredients, and internal and external audit reports.

3.3 A BRIEF SCENARIO ON THE PROPOSED BLOCKCHAIN PLATFORM

The process starts with the registration of actors, assets, smart contract, and transactions details on the platform through an admin panel on Hyperledger Network. The first transaction occurs via supplier of raw materials. Main raw materials for the production of Kashar cheese are milk, packaging material, and other ingredients like aroma, water, etc. Data generated by supplier is recorded on the system where a contractual agreement is triggered. Raw materials are transformed into assets with party IDs attached to the supplier generated data (supplier ID). Suppliers put all required data (mentioned under previous heading) on the Hyperledger platform through given access key. Then, certifications are controlled or created if necessary and uploaded to the system. External audit reports and certification processes are conducted by regulatory bodies at specific time intervals to check if the manufacturer has proper conditions to produce Kashar cheese, e.g., if the machinery is proper, if the employees are trained, if the temperature and other location conditions are fulfilled for cheese production, if the hygiene conditions are fulfilled, if minimum nutritional requirements are fulfilled, if labeling is correct and reliable, etc. After, procurement of raw material, party ID is given, and it is converted into an asset for smart contract suitability. Raw material with specific party ID is pooled in tanks and processed through boiling, filtering, curding, wet boiling, molding, and packaging. New party IDs are attached to the semi-product and finished product at relevant processed. All data generated through these processes are recorded on the Hyperledger platform. Track of processes are done through these party IDs immutably recorded on the system. At the packaging process, relevant data required for end customer is recorded on the packaged through QR Code technology. It is a simple code scanned via mobile phones that lead the end customer to the application platform where they access finished product information within permissions. After finished product stage, product is distributed to either warehouses or retailers. Distribution data is also recorded on the platform with details of time, distributor IDs, transportation/warehousing conditions, etc. Below Figure 3.2 is the architecture of Hyperledger platform for cheese manufacturing company.

Figure 3.2: Hyperledger architecture for cheese manufacturing company



3.4 CONCEPTUAL MODEL DESIGN

After we specified the model components, it is time to set up for conceptual design where we explain design elements and relationship between elements. Design elements are grouped into three categories as actors, assets, transactions, and inquiries. Actors are already defined under Heading 3.2.1. We only add admin as the major controller of the platform. Assets are the representative form of products and materials on the platform language. Assets include products, product movements, and contract determining the conditions. Transactions are the activities of actors represented on the platform with terminology created with platform language. Transactions are recorded on the ledger and cannot be reversed. Inquiries are the ask command to retrieve specific data like asset owner, location, etc.

Next step is to determine the permissions to satisfy security and access requirements of the model. It basically defines who can do and see what on the platform. It also specifies the management of data pertained to the actors, transactions, and assets. Admin is able create, edit, delete, read, and evoke inquiries on the platform. Regulatory actors, on the other hand, have read permission to all data recorded on the ledger to be able to correctly audit and certify the company for ensuring authenticity and safety. Please see Table 3.4 and Table 3.5 for detailed tables including transactions, permissions, and recorded data.

Table 3.4: Data entries pertained to design elements

Design Elements	Data Generated
Actors	Company ID, Brief Description, Contact Information, Financial Statements, Location (Valid for all actors)
Assets	Party ID, Type, Name, Description, Condition, Owner Details, Status, Time Stamps,
Movements	Movement ID, Tracking No, Extra Notes, Status, Holder Information, Time Stamps, Location, Financial Records
Contracts	Contract ID, Agreed Terms and Conditions regarding Payment, Delivery, Damage, Quantity, etc., Actors Involved

Table 3.5: Transactions and permissions

Transactions	**Permissions**
CreateActor UpdateActor UpdateContract DeleteActor EndContract	Admin only
CreateAsset	All actors except regulatory bodies and customers
CreateMovement CreateContract	All actors except customers
UpdateAsset DeleteAsset TransformAsset	Owner only
UpdateMovement DeleteMovement TransformMovement ReadTemprature	Holder only
ReadActor	Regulatory bodies, certifiers, data owners, customers can only read number of actors, and permissioned actor information open to public
ReadAsset ReadMovement CountActors CountAssets CountMovements	All actors

4. CONCLUSION

In this thesis, a conceptual blockchain model is designed for Kashar cheese food chain traceability after a detailed literature and concept research are conducted on food chain traceability and blockchain technology. Main aim of the study is to answer the question "Is blockchain technology an alternative traceability system for food supply chains?" For finding answer to the question, a blockchain framework on Hyperledger platform is designed on a dairy food (Kashar cheese) supply chain system. This study differentiates from the previous studies in ways that it utilizes from developing technologies and brings a new approach to the existing traceability systems.

It is understood that there is no standardized way of building a traceability system for food chains. The sector also lacks proper and standardized legal framework. Terms and conditions regarding a good traceability system should satisfy are not well defined. Roles and responsibilities of chain stakeholders from supplier to the end customer are not specified within the traceability requirements and practices. To enable full traceability across food supply chains, it is important to keep good record of data and synchronize data on the network where all participants can reach within permission limits. However, theory does not fit practice all the time. Even, those companies utilizing last software technologies might face synchronization issues, reliability of data they record, and a good network communication. Absence of guidance on how to build a good traceability system is another issue. Especially, in our country, the way traceability system is developed or designed is left to the practices and no guidelines are provided. Bullwhip effect is an urgent issue affecting costs-profit ratio in a bad way too. This issue is sourced back by the problem of not having a proper traceability of inventory and processes.

Security and traceability of food supply chains is vital to societal wellness since any discrepancy on the chain will have tremendous effect on population as well as corporate images of suppliers, manufacturers, and retailer. A well-designed traceability system enables to intervene at the right time before it evolves into a disaster. Product recalls and management of foodborne outbreaks get easier and efficient if a proper traceability system, where all actors and actions are traceable, exists. Gaining trust is another hurdle on the tables of businesses. Building a trustworthy relationship might take long time but sustaining it gets harder as major food scandals occur. Therefore, a transparent network on which full traceability is provided would help companies to build trust easily and faster than before.

Blockchain technology popularized with Bitcoin at first but evolved into a different way doing business. Technology rather than the cryptocurrencies is gaining attention of various business sectors. It is a promising technology for an upcoming decentralized, distributed world. Yet, it is not a key to every lock since it is a developing technology that needs room for improvement and testing to be understood and applied in the best way possible. It carries limitations and poses concerns of scalability, applicability, sustainability, expertise, etc. As new models are developed and tested, the features and characteristics of the technology would be better comprehended and improved to satisfy future needs and requirements of businesses and customers in the future. This thesis serves this purpose of developing a design to be tested to better understand the details and working logic of technology in the field of supply chain.

This thesis contributes to the literature and practice as it deeply examines the terminology and basics of blockchain technology, terminology of traceability and major traceability models designed previously, and advantages and disadvantages of both technology and traceability systems from food supply chain perspective. The requirements a traceability system needs to establish upon is determined. The participants of the system are determined and explained in detail in terms of actions and roles they pertain. The transactions to be generated and traced are defined. Platform comparison is provided by examining the features they provide.

Proposed model in this thesis is a starting point to understand requirements, participants, internal and external factors of production, distribution processes, and customer perspective. The conceptual model gives insight on the origin of finished products, full track of processes, time frame through processes, and the network structure of a food manufacture. It provides transparency to the food supply by enabling traceability within permission limits. Food safety concern is partially eliminated with the proposed blockchain model. Immutable and distributed structure of platform builds trustworthy and reliable network among stakeholders. Information asymmetry causing a lot of pain for the supply chain stakeholders is eliminated as all stakeholders are gathered under a distributed network where information is communicated real-time. Keeping a good record of data which is immutable and traceable all along the chain enhance decision making practices too. Key strategies would be established by analyzing the recorded data on the platform. Better forecast of demand and inventory, better analysis of costs and market price dynamics, and being innovative are among the possible benefits of utilizing a good traceability system based on blockchain.

4.1 LIMITATIONS AND FURTHER RESEARCH SUGGESTIONS

Testing the model design is one of the major limitations to the study. It would reveal better practical implications to the business as there is limited model designs and pilot studies conducted at the time being. Other limitation is the complex multi-stakeholder structure of food chains. This model coverage is limited to supply flow of Kashar cheese only. Model coverage would be broadened to the whole product segments. Also, most of the companies are engaged with international trade. A model developed with international coverage would give a different approach and implementation opportunities for businesses and technology developers. System requirement determination is also limited to the literature and case studies revealed by pioneering companies. A multiple case studies backed by sectoral questionnaire analysis would give deeper insight to the sectoral and systematic requirements in food supply chains. The maturation level of blockchain technology is another limitation as we have limited platform options and features. As new blockchain platforms or new features to the existing platforms are developed, the way the traceability model design would be affected and transformed. Blockchain based systems require full participation from every actor on the chain, but it is not an easy task to make everyone involved although it promises many benefits. Most of the companies operating in the sector are small medium enterprises and the initial cost of building a blockchain network is very high for now. Thus, SMEs are facing high investment costs that they would not bear. Future research suggestions after this thesis would be to conduct a simulation or real-case testing of the model, to dive deep into the model requirements through quantitative research from all stakeholder perspectives, to broaden the data generated and smart contract aspects of model, to analyze other blockchain platforms like Oracle, Ambrosus, Ethereum 2.0 etc., to evaluate model through performance measures derived from model requirements, and lastly to compare existing traceability software with the proposed blockchain model after testing.

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