



Blockchain-based Framework for Supply Chain of Agri-food Sector in Malaysia

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Blockchain-based Framework for Supply Chain Management of Agri-food Sector in Malaysia

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DECLARATION

I declare that the work in this thesis was carried out in accordance with the regulations of Universiti Malaysia Sarawak. Except where due acknowledgement has been made, the work is that of the author alone. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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ABSTRACT

In the advent of blockchain technology, buzzword such as bitcoin, cryptocurrency and blockchain is gaining a lot of hypes around. As the enabler for cryptocurrency, the technology of blockchain is vastly applicable in different field, one of the most promising is supply chain. Recent research shows a lot interest on blockchain applying into supply chain, but most of them is covering the use case using public blockchain like Ethereum. Public blockchain is accessible for all user but feature like this might not be suitable for the use case of supply chain management as it involves unrelated party in the supply chain network. While some studies involve the implementation of blockchain based for supply chain solution, there is a gap on relating blockchain to supply chain transparency and traceability in quantitative approach. Quantitative approach is very meaningful in this study as it provides more clarity compared to qualitative approach in existing research. The first focus of this research is to investigate the differences between public and private blockchain. Secondly, this research proposed a framework to determine the transparency and traceability of each blockchain solution with the use case of supply chain of pepper industry in Malaysia. This study has presented results of traceability and transparency in a quantitative approach for both public blockchain, which is Hyperledger Fabric and Sawtooth. The result shows that Sawtooth able to achieve higher transparency and traceability than Fabric in most cases.

Keywords: Blockchain, supply chain, transparency, traceability

Kerja Berasaskan Blok Rantai untuk Pengurusan Rantaian Bekalan Sektor Agri-Makanan di Malaysia

ABSTRAK

Melalui kemunculan teknologi blok rantai, terma seperti bitcoin, kriptowang dan blok rantai menjadi semakin popular. Selain teknologi kriptowang, teknologi blok rantai terdapat banyak aplikasi dalam bidang yang luas, salah satunya ialah untuk bidang rantaian bekalan. Penyelidikan terkini lebih mengkhusus kepada teknologi blok rantai yang berkait dengan rantaian bekalan, tetapi kebanyakannya meliputi kes penggunaan menggunakan blok rantai awam seperti Ethereum. Blok rantai awam boleh dicapai oleh semua pengguna, tetapi ciri seperti ini mungkin tidak sesuai untuk kes penggunaan pengurusan rantaian bekalan kerana melibatkan pihak yang tidak berkaitan dalam rangkaian rantaian bekalan. Walaupun beberapa kajian berjaya mengimplementasi rantaian bekalan berasaskan blok rantai, kebanyakannya tidak menjelaskan bagaimana blok rantai membekalkan ketelusan dan kebolehkesanan rantai dalam pendekatan kuantitatif. Pendekatan kuantitatif sangat bermakna dalam kajian ini kerana memberikan lebih kejelasan berbanding dengan pendekatan kualitatif seperti yang disediakan oleh kajian yang ada. Perkara pertama yang ingin ditumpukan kajian ini adalah perbezaan blok rantai awam dan blok rantai swasta. Selain itu, kajian ini menentukan ketelusan dan kebolehkesanan setiap aplikasi rantaian bekalan industri lada di Malaysia. Kajian ini telah membentangkan hasil pengesanan dan ketelusan dalam pendekatan kuantitatif untuk kedua-dua blok rantai umum, iaitu Hyperledger Fabric dan Sawtooth. Hasil kajian menunjukkan Sawtooth dapat mencapai pengesanan dan ketelusan yang lebih tinggi daripada Fabric dalam kebanyakan kes.

Kata kunci: *Blok rantai, rantaian bekalan, ketelusan, kebolehkesanan*

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LIST OF ABBREVIATIONS

1PL	First Party Layer
2PL	Second Party Layer
3G	Third Generation
3PL	Third Party Layer
4G	Fourth Generation
4PL	Forth Party Layer
5G	Fifth Generation
5PL	Fifth Party Layer
BFT	Byzantine Fault Tolerance
CA	Certificate Authority
CFT	Crash Fault Tolerance
dApps	Decentralized Application
DPoS	Delegated Proof of Stake
ERP	Enterprise Resource Management
EVM	Ethereum Virtual Machine
FBA	Federal Byzantine Agreement
GPS	Global Positioning System
IoT	Internet of Things
JAKIM	Jabatan Kemajuan Islam Malaysia
MSP	Membership Service Provider
P2P	Peer to Peer
PBFT	Practical Byzantine Fault Tolerance

PKI	Public Key Infrastructure
PoA	Proof of Authority
PoET	Proof of Elapsed Time
PoS	Proof of Stake
PoW	Proof of Work
QR Code	Quick Response Code
RFID	Radio Frequency Identification
RPCA	Ripple Protocol Consensus Algorithm
RW	Read Write
SCM	Supply Chain Management
SOLO SBFT	Simplified Byzantine Fault Tolerance
WSN	Wireless Sensor Network

CHAPTER 1

INTRODUCTION

1.1 Research Background

Koo, Othman, Moy and Khor (2017) said that agribusiness, the business of agri-food sector contributed around 8.6 percent of Gross Domestic Product in Malaysia and become one of the key contributors in economy of Malaysia. One of the notable agrifood, pepper, also known as King of Spices, has been exported with a tremendous amount that worth RM490.20 million to Japan, China, Hong Kong, South Korea, Taiwan and Singapore in 2016 (Mah, 2017).

However, there are certain challenges faced by this industry. Fletcher (2017) reported that near the border with the Camar Bulan village at West Kalimantan, up to one hectare of land in the Samunsam Wildlife Sanctuary Sarawak has been turned into pepper farms illegally by the Indonesians who live there. The pepper industry in Malaysia has produced jobs and income for about 67,000 farming families and households. Mah (2017) mentioned that many pepper farmers from Sarawak still depend on crops of pepper as their main source of income. This highlighted the importance of transparency and traceability in supply chain management to ensure that all production of agri-food is from authorized sources for the sake of income of the farmer and economy of the country.

Supply chains are a series of linked suppliers and customers until products reach to customer (Ernest & Handfield, 2002). A strong supply chain management consists of both traceability and transparency. Supply chain transparency is the extent to where all stakeholders have a mutual understanding and access to the information that they request

without delay, loss, distortion, and noise (Hofstedel, 2005; Deimel et al., 2008). Aung and Chang (2014) explain traceability in terms of what, where, why and how aspects of a product along the supply chain. An effective food traceability system able to manage food quality, safety risks and developing Food Supply Chain management (Manzini and Accorsi, 2013). Recently, supply chain industry is exploring blockchain technology and some even suggests that it might have positive impact to the transparency and traceability of supply chain management.

Blockchain is a distributed ledger that is used to store transaction record and share across in a business network (Gupta, 2017). Every record is encrypted before stored in a decentralized manner and trackable which meets the requirement of a transaction that is secure and fast. There are some building blocks in a blockchain. First is consensus, stakeholders in the blockchain network must follow an agreed protocol to validate a transaction creation. Second is provenance, the source of information of a transaction in a blockchain network is traceable. Third is immutability, it is not feasible to tamper the information of a transaction once it is validated and stored in the blockchain. Furthermore, blockchain has another feature that act as a digital agreement called smart contract (Surasak et al., 2019).

Bitcoin which is currently one of the most popular cryptocurrencies is running on blockchain (Meng and Yaou, 2018). However, the ability of blockchain is far beyond creation of cryptocurrency and theoretically it can be utilized into supply chain management to tackle certain issues. A systematic review will provide understanding of blockchain technology in depth (Wang et al., 2019). This is where this study came in, to understand on how blockchain will benefit the current supply chain scenario on agri-food in Malaysia.

1.2 Problem Statement

Supply chain of most industries have been operating in centralized model for decades. With the approach of centralized model of recording transactions and tracking assets, every participant on a network keep their own ledgers and records (Gupta, 2017). This is causing issues like lack of information about the origin of the products for the consumer (Casado-Varaa et al., 2018). Therefore, transparency in supply chain management is crucial as information could be altered purposely or accidentally without acknowledging the relevant party in the supply chain network.

Most of the existing supply chain managements practice strong traceability but overlook transparency (Nakamoto, 2008; Lee, 2013; Swan, 2015). This lack of transparency is usually intentional as some participants want to hold their competitive advantages from competitors such as a supplier who delivers quality products on time with significantly lower cost (Bateman & Bonanni, 2019). This could result in delays and defaults during the delivery of goods.

1.3 Objectives

The aim of this research is to design and develop a blockchain based framework that consists of transparency and traceability for supply chain management of agri-food sector in Malaysia.

Other objectives include:

- i. To study the list of blockchain technologies (public blockchain such as Ethereum and private blockchain such as Hyperledger) and determine which is most suitable to apply to the solution.

- ii. To evaluate the transparency and traceability of the blockchain technologies at (i) using the proposed solution in a quantitative approach.

1.4 Scopes of Study

Blockchain technology remain in infancy stage, however it is gaining momentum within certain fields especially supply chain, where factor of trust is predominant on driving adoption. Blockchain is bringing value to supply chain management in these areas which are transparency, traceability, disintermediation, digitalization, improved data security and smart contracts (Wang et al., 2019). This study will focus on transparency and traceability.

On the other hand, the exploration of permissioned blockchain is also a major purpose for this study. This is due to there are certain differences among public blockchain and private blockchain, for instance both are using different consensus algorithm to approve creation of new transaction. Not only that public and private blockchain behave differently, the distinction among them could affect the transparency and traceability. For the reason of making comparison, this study will adopt two blockchain framework. Although it is possible that adopt more blockchain framework in the study could be giving better insights on comparison, but the whole point of the research is to show that different blockchain could affect transparency and traceability, hence two blockchain frameworks are ample to fulfil the purpose.

In the domain of supply chain of agri-food sector, this study will focus on the supply chain of pepper as the case study. The environment for implementation and analysis of each of the proposed framework will model the supply chain process as much as possible from the information gathered.

1.5 Significance of Research

Contributions of this study can be described as below:

- i. The proposed blockchain based supply chain solution implements two different private blockchain technologies with different blockchain component such as consensus algorithm, smart contract technology, database management and peer's management.
- ii. The results of proposed solution will be analysed base on a supply chain transparency and traceability framework.

1.6 Outline of the Thesis

Chapter 1 describes the background of the research, problem statement, objectives of the project and scope of the research. Chapter 2 discuss the conventional supply chain process of pepper, the definition of supply chain traceability and transparency, blockchain technology according to sources from the official website, related journal, and articles. Chapter 3 discusses about the exploration of blockchain technology and development of solution for the study. Chapter 4 discusses about the implementation and testing of the proposed solution to determine its traceability and transparency. Chapter 5 provide a summary of the study, it consists of the description of limitations, contributions, and future work of the research.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

Supply chain is the management of funds, raw materials, components, and finished products, as it moves from suppliers, to manufacturers, wholesalers, retailers, and consumers. Figure 2.1 illustrates the overview of supply chain management of agri-food (pepper) in Malaysia (Caro et al., 2018). The main phases characterizing a generic agri-food supply chain which consists of 5 participants and how products flow in the supply chain network.

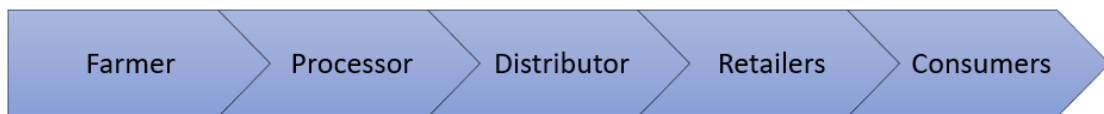


Figure 2.1: Typical supply chain in the retail industry in Malaysia

The role of farmer is farming and harvesting the product and then send it to the processor. Processor could have multiple roles depends on the type of food or product in the supply chain network. For instance, the product of pepper will undergo process of fermentation, washing, drying, and grinding. Before transfer the product to distributor, it will be packaged and certified by JAKIM for halal certification, all these processes might involve one or more than one processor. Distributor mainly in charge of warehousing and storage of all the packaged product to be then distribute to other party such as retailer, wholesaler, or other channel so that product is accessible for consumer.

The high-level representation of the supply chain management from Figure 2.1 look simple however there is a comprehensive of logistic take place behind the scenes when a product flow from one party to another. To bring trust into the system it requires third party authorities (Alkhodre et al., 2019). In real world scenario, when farmer transfers harvested crops to a processor, the whole process usually involving another entity (a middleman) in the supply chain network known as trusted third-party logistic provider as shown in Figure 2.2.

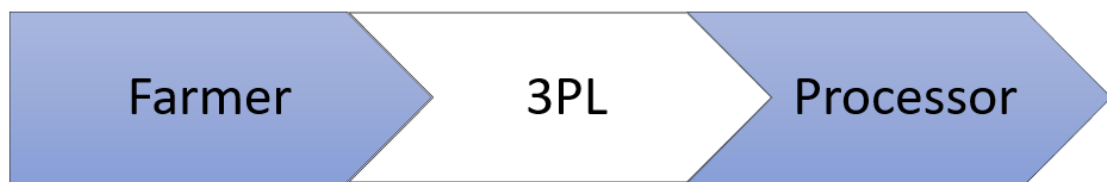


Figure 2.2: Third Party Logistic (3PL)

According to Chetak Logistic (2015) first party logistic (1PL) is referring to a firm that makes certain shipment from location A to location B by the firm itself, the firm itself has the control of all the logistic process. Second party logistic (2PL) refers to a firm that rents the transportation service from a service provider to get the shipment done, while the firm still has control of all the logistic process. Third party logistic (3PL) is a firm that outsources part or all the logistic work to a service provider. One of the roles of 3PL that distinguish itself from 2PL and 1PL is to facilitate trust in the supply chain process such as certifying raw materials, components, or finished products, as they travel through the supply chain. The reason of a 3PL is involved in the supply chain network is due to systems operating in a centralized model, where all transactions are executed through a trust-based system making all participants dependent on the third party (Nakamoto, 2008; Lee, 2013;

Swan, 2015). The implication of the modern systems operating in a centralized model is that the execution of transactions is dependent on a third party i.e. both the supplier and consumer rely on the third party for the exchange of goods or services.

Laney (2018) point out that current supply chain management consists of certain weak points. These weak points happen when there are multiple enterprise resource planning (ERP) systems in use across different organisations as data does not flow well via interface points between systems or individual ledgers during transference of ownership or change in status between two parties. Thus, data transparency is limited at the hand-off points of raw materials, components, funds, and finished products.

Le et al. (2019) mentioned that every types of business can participate in the blockchain network and use the features of the blockchain system to ensure transparency of participants. Le et al. (2019) also believed that blockchains is able to solve the weak points of current supply chain management by eliminating the need for a 3PL to account for transactions and good among other data or at least reduce its role to 2PL or 1PL because all participants have access of untampered past transactions in the blockchain network .

2.2 Supply Chain Transparency and Traceability

Traceability and transparency are often used as interchangeable terms during discussion of supply chain management. In order to develop a useful solution for supply chain management, it is important to find out differences between these terms as both are different indicators of a good supply chain management system.

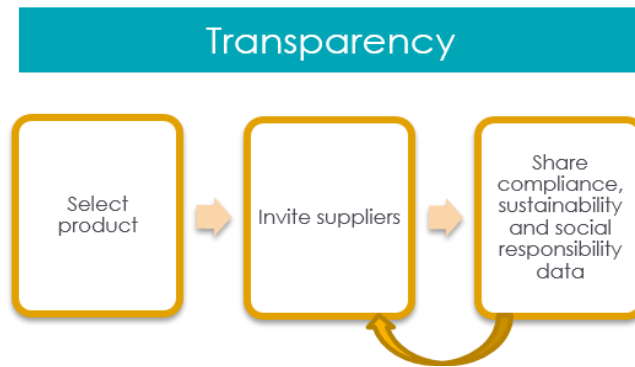


Figure 2.3: Supply Chain Transparency (Tsai, 2018)

Transparency has been defined as the disclosure of information (Egels-Zandén et al., 2015; Doorey, 2011; Mol, 2014) that enables fair competition (Akerlof, 1970), profitable business ventures (Tapscott et al., 2003), and company fulfilment regarding sustainability efforts (Kaptein et al., 2003; Kaynak et al., 2012). According to Tsai (2018), supply chain transparency captures high-level information about a supply chain a product such as product components, names of suppliers, locations, associated certifications, etc. In other word, transparency decide the breadth of the information or disclosure of information that can be exposed to a certain party. Base on Figure 2.3, supply chain transparency enables participants identify all the suppliers for all the components in a product, down to the provenance. Supply chain transparency also enables participants in the supply chain network to identify and collect previously unknown product information and/or communicate and establish specific requirements. Thus, all the participants can gain better visibility of their global supply chains and ensure compliance with safety, sustainability, and social responsibility requirements.

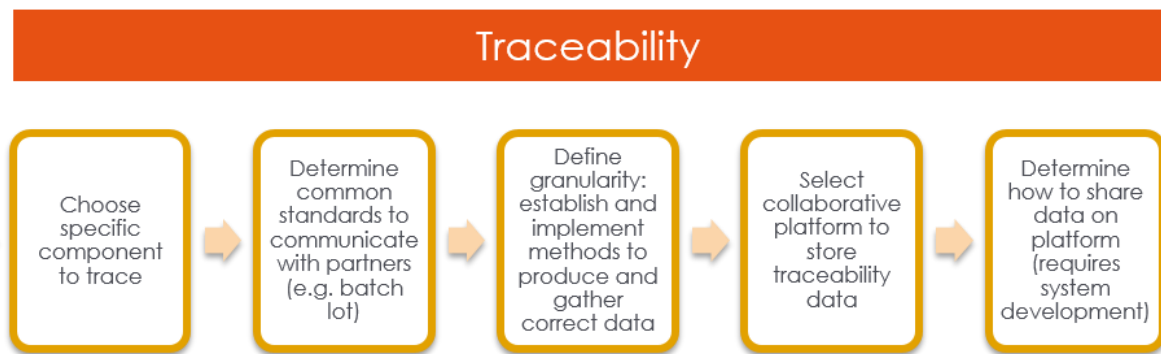


Figure 2.4: Supply Chain Traceability (Tsai, 2018)

From Figure 2.4, Tsai (2018) mentioned that supply chain traceability captures much more granular information about a product component, such as batch-lot data (harvest date, field data, etc.), purchase order data, and other operational information. Unlike supply chain transparency, the focus of traceability is less on mapping the entire end-to-end supply chain but on following flow of product components or purchase orders as it move through the supply chain. The granularity of the data used in traceability allows more targeted recalls, reducing scale and cost.

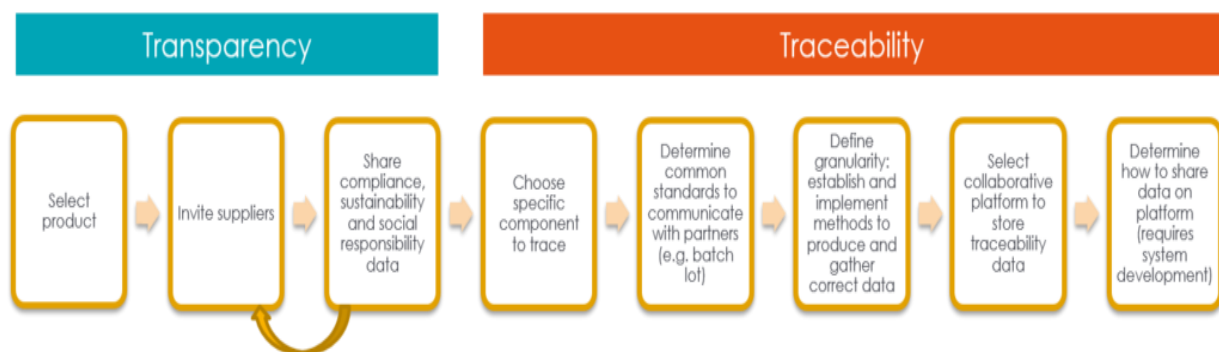


Figure 2.5: Supply Chain Transparency and Traceability (Tsai, 2018)

From Figure 2.5, Tsai (2018) depicts the relationship of supply chain transparency and traceability that is traceability relies on transparency. Transparency must come first

before traceability data can be collected. Without transparency it is not practical to implement traceability. For example, granular information such as batch, operational data, purchase order data is almost impossible to gather without information of supplier. Successful supply chain management of requires traceability that is built upon complete transparency.

2.3 Blockchain

According to Hyperledger (2018), a blockchain is a peer-to-peer distributed ledger forged by consensus, combined with a system for "smart contracts" and other assistive technologies. Yaqoob et al. (2019) explained that blockchain is a peer-to-peer distributed network without any third party or intermediary. Peer-to-peer is a class of systems or applications that harness distributed resources to perform certain functions in a decentralized manner (Stoica et al., 2003). Consensus is a process that add a new block to the blockchain network from an entitled node (Neisse, Steri, & Nai-Fovino, 2019). Smart contract is a computer program that enforce rule without involving third party (Westerkamp, Victor, & Küpper, 2018). Blockchain can be categorised as public blockchain and private blockchain, due to these differences the two blockchains will operate under different consensus algorithms for different purpose.

2.3.1 Public Blockchain vs Private Blockchain

In public blockchains (permissionless) anyone can join as regular user or miner. All participants can perform transactions or operate under conditions pre-set in smart contracts (Casinoa, 2019). Bitcoin is the pioneer of public blockchain platform. It is the first cryptocurrency unveiled using blockchain as the backbone of the infrastructure to store transaction data in an untampered manner with hash algorithm make it even more secure. A

public blockchain network like bitcoin is accessible to anyone around the globe, anyone can make transaction with bitcoin and anyone could be the miner in the bitcoin blockchain network under proof of work consensus protocol. As for private blockchain, the network is being controlled in terms of involvement of participants and their access to the data. To further clarify the differences, the following explanation put Ethereum (an instance of public blockchain) and Hyperledger Fabric (an instance of private blockchain) in depth comparison.

Ethereum is the most popular blockchain alternative of Bitcoin which borrows heavily from the Bitcoin architecture. It is a public blockchain with a built-in cryptocurrency called Ether. What distinguish Ethereum from Bitcoin is that Ethereum is an open source platform that enables developers to build and deploy decentralized applications (dApps). Due to dApps is independent on central server or third party for operation, it does not have any central point of attack (Duong-Trung et al., 2019). On the other hand, Ethereum has smart contracts that define rules and penalties around an agreement and enforces those obligations. Smart contracts are treated as autonomous scripts or stateful decentralized applications that are stored in the Ethereum blockchain for later execution. Instructions embedded in Ethereum contracts are paid for in ether (or more technically "gas") and can be implemented in a variety of scripting languages. Ethereum currently uses a proof of work (PoW) protocol but the plan is to update its network to proof of stake (PoS). There are other emerging public blockchain such as Ripple, Stellar and many more but what makes Ethereum stand out from the crowd is its design of purpose (Bambrough, 2019). Other than establish cryptocurrency via Initial Coin Offering, Ethereum serves more like a general blockchain for a variety of purposes by supporting creation of dApps and smart contracts is EVM infrastructure (Hayes, 2019).

Hyperledger Fabric is a permissioned blockchain infrastructure providing a modular architecture with a delineation of roles between the nodes in the infrastructure, execution of Smart Contracts and configurable consensus and membership services. Consensus is pluggable for Hyperledger Fabric depending application specific requirements, various algorithms can be used hence no mining is required.

Table 2.1: Ethereum vs Hyperledger Fabric (Richardson, 2017)

Characteristics	Ethereum	Hyperledger Fabric
Founded Date	July 2015	July 2017
Currency	Ether	None
Governance	Ethereum Developers, Enterprise Ethereum Alliance	Linux Foundation, IBM
Consensus	PoW (Proof of Work)	PBFT (Practical Byzantine Fault Tolerance)
Network	Permissionless, Public	Permissioned, Private

The most essential distinction between Hyperledger and Ethereum is the intent they are designed as shown in Table 2.1. Ethereum runs the Smart Contracts on the EVM for applications that are attributed to being decentralized and are for mass consumption. EVM stands for Ethereum Virtual Machine is use for virtual stack that have to install in the network node to execute bytecode of smart contract (Prasanna, 2019). On the other hand, Hyperledger leverages blockchain technology for business. It is designed to support pluggable

implementations of components delivering high degrees of confidentiality, resilience, and scalability. Hyperledger has a modular architecture and provides a lot of flexibility in how you want to use it. Its extensible architecture provides futuristic solutions for enterprise blockchains.

2.3.2 Consensus Algorithms

A consensus mechanism in blockchain is playing a crucial role on generating and validating a transaction. Consensus algorithm can be categorized according to the type of network of blockchain, either public or private (Khan, Balan, Javed, & Tarmizi, 2019). Cryptocurrency is one of the main factors that determine what kind of consensus work for public blockchain as some mining process is required. On the other hand, consensus in private blockchain has more conserved approach on involving the nodes for validation of transactions.

2.3.2.1 Public Blockchain Consensus

Most of the public blockchain like Bitcoin and Ethereum is using Proof of Work (PoW) consensus algorithm to create and approve new transaction in the blockchain network. Public blockchain platform usually has their own cryptocurrency, such as bitcoin and ether. These cryptocurrencies will be rewarded to a miner whoever solved complex computational puzzle that led to creation of new block in the blockchain network. However, PoW is facing some criticism, Kumar (2018) mentioned that it consumes a lot energy given the computationally heavy algorithm. In addition, PoW has a high latency of transaction validation, and the concentration of mining power is located in countries where electricity is cheap, hence making it unsustainable in the long run.

Bitcoin and Ethereum foreseen this issue thus they proposed another consensus algorithm for their system named Proof of Stake (PoS). Under this algorithm there are no more miner involved in the creation of new block, but they are known as “validator”. Rather than mining the blockchain, they validate the transactions to earn a transaction fee and no mining is required, the creator of a new block is chosen in random, depending on the validator’s wealth which is also defined as ‘stake (Kumar, 2018). However, this algorithm comes with another problem which is known as “Nothing at Stake”.

2.3.2.2 Private Blockchain Consensus

Hyperledger Sawtooth is a private blockchain developed by Intel is using Proof of Elapsed Time (PoET) consensus algorithm. Instead of mining, PoET works in a hybrid of random lottery and first come first serve basis. Every validator will request a wait time for creation of new block, the validator with the shortest wait time for a particular transaction block is elected as the leader and appointed to create the new block (Kumar, 2018).

On the other hand, there are Crash Fault Tolerant (CFT) and Byzantine Fault Tolerant (BFT) that quite a few consensus algorithms inherit from, both of it is different but relatable. According to Jain (2018), the definition of CFT can be understood as a system that is tolerant to component (software or hardware) malfunctioning. Kafka and Solo are instances of CFT which both serves as consensus algorithm in Hyperledger Fabric platform. In a blockchain network, Kafka and SOLO works as orderer that determine which transactions to add into the blockchain in what order, and due to it is a CFT based solution it will still allow transactions happened when some of the nodes in the blockchain is down. For instances of BFT, there are Practical Byzantine Fault Tolerant (PBFT) and Simplified Byzantine Fault Tolerant (SBFT) which both will further explains below.

The Practical Byzantine Fault Tolerant (PBFT) first assumes that there are independent node failures and manipulated messages propagated by specific, independent nodes (Coyler, 2015) in a blockchain network. All the nodes in the PBFT are ordered in a sequence with one node being the primary node (leader) and the others referred to as the backup nodes. For the PBFT model to work, the assumption is that the number of malicious nodes in the network cannot simultaneously equal or exceed $\frac{1}{3}$ of the overall nodes in the system (Coyler, 2015). PBFT works effectively and safety as long as at most $(n-1)/3$ nodes, where n represents total nodes, are malicious or faulty at the same time (Coyler, 2015). Coyler (2015) PBFT consensus (called views) comes down to 4 phases as below:

1. A client sends a request to the leader node to invoke a service operation.
2. The leader node multicasts the request to the backup nodes.
3. The nodes execute the request and then send a reply to the client.
4. The client awaits $f + 1$ (f represents the maximum number of nodes that may be faulty) replies from different nodes with the same result. This result is the result of the operation.

The Simplified Byzantine Fault Tolerant (SBFT) is an improved consensus algorithm over PoW for permissioned network blockchain. SBFT involves a validator who bundles proposed transactions and forms a new block. Unlike the Bitcoin blockchain, the validator is a known party, given the permissioned nature of the ledger, consensus is achieved as a result of a minimum number of other nodes in the network ratifying the new block (Randall, 2018). In order to be tolerant of a Byzantine fault, the number of nodes that must reach consensus is $2f+1$ in a system containing $3f+1$ node, where f is the number of faults in the

system. For example, if we have 7 nodes in the system, then 5 of those nodes must agree if 2 of the nodes are acting in a faulty manner (Randall, 2018).

Proof-of-Authority (PoA) is a consensus algorithm which can be used for permissioned network blockchain. It uses a set of ‘authorities’, which are designated nodes that can create new blocks and secure the ledger. Ledgers using PoA require sign-off by majority of authorities in order for a block to be created (Randall, 2018).

It is crucial to identify which consensus algorithm will be the most suitable to apply in the solution. For instance, CFT, BFT and PoA might be more suitable than to implement in the solution compare to PoW and PoS as it does not require mining process that consume heavy computational power which is not needed in a supply chain transaction when creating new block.

2.3.3 Hyperledger

Other than Hyperledger Fabric there are some other private blockchain framework such as Quorum, Ripple, NEM, R3 Corda and other private blockchain framework. However for the purpose of proof of concept, Fabric and Sawtooth are preferable in this study as both of the blockchain framework is under the same governance from Hyperledger community, hence it is more appropriate to make comparison among them as they have their own differences but might share certain similarities.

There also other blockchain framework under Hyperledger, such as Burrow, Indy, Iroha, and Besu. Moreover, some of these blockchain is still in early phase of development and far from production ready environment.

According to Hyperledger (2018), Hyperledger is an open source collaborative effort created to advance cross-industry blockchain technologies. It is a global collaboration, hosted by The Linux Foundation, including leaders in finance, banking, Internet of Things, supply chains, manufacturing, and Technology.

There are currently 6 blockchain frameworks under the umbrella of Hyperledger, which are Fabric, Sawtooth, Iroha, Indy, Besu and Burrow (Hyperledger, 2018). Each of this framework established in different time and have unique features of its own. Among them Fabric is the earliest and most mature framework when comes to stability and popularity adoption, Sawtooth comes close to Fabric as second most mature, the rest of them are still under incubation stage. However, some of these frameworks are designed for certain use cases unlike a general blockchain framework like Fabric and Sawtooth.

Fabric and Sawtooth will undergo review to determine which is best suited for the development of framework in this study, whereas the rest of the framework which is still under incubation stage will not be considered.

2.3.4 Hyperledger Fabric vs Hyperledger Sawtooth

In the exploration of framework of Hyperledger Fabric and Hyperledger Sawtooth, there are a few key differences that are clarified in Table 2.2 which are used as references to determine which of it is best adopted for the framework in this study.

Table 2.2: Differences of Hyperledger Fabric and Hyperledger Sawtooth

Differences of components	Hyperledger Fabric	Hyperledger Sawtooth
Consensus algorithm	Kafka	Proof of Elapsed Time (PoET)
Network Infrastructure	Permissioned	Permissioned or Permissionless
Governance	More restricted with Membership Service Provider (MSP) feature	More open approach on adding roles to the network
Privacy	Comes with “Channel” feature that only show related ledger (information) to relevant party in the network	All the party in the network has read access to all the ledger in the joined network

Both consensus algorithm of the framework has its own built-in consensus algorithm. The main concern of deciding which consensus algorithm to be implemented is whether it is requiring mining process, since both consensus algorithms is not performing mining hence both is suitable to opt in for solution of this study.

One of the unique infrastructure characteristics of Sawtooth is the network can be permissioned or permissionless. Fabric has a built-in Membership Service Provider (MSP) feature which promote better governance than Sawtooth. Any party must undergo MSP

system for identity verification to join the network. Digital certificate will be issued to each of them for further verification to perform every transaction.

Fabric has a feature, “Channel” which serve the purpose of organising the information in need to know basis (Rilee, 2018). Unlike Sawtooth, once a party gain access to the blockchain network, it also gains read access to all the information throughout the whole network. With Channel, only related ledger is appending on the relevant parties, but other data remain accessible to other party. Hence it will maintain the confidentiality of data but might prone to less transparency of data.

2.4 Related Works of Blockchain on Supply Chain

Although blockchain technology is gaining a lot of hype, but it is still not a hot trending field of research (Razzaq et al., 2019). A number of researches are extracted for the support of this study. From recent literature, there are wide range of approaches on applying blockchain technology on supply chain, all of it can be categorised in three categories.

First category is more about exploring the potential of blockchain and find out whether can it be applied in supply chain domain. Studies like this mostly emphasize on the requirement gathering and analysis and feasibilities study. Second type of research is carried out on top of first category of research and then formulate a theoretical framework but without much technical implementation. Third category of research is carried out on top of first and second category research then implement the framework or solution, regardless of the type of blockchain that will be applied. Third category of research’s finding are mostly about only the implementation of blockchain, but without any validation on the outcome of the research.

2.4.1 RFID and Blockchain Based Supply Chain System

In the effort of applying blockchain in supply chain, Feng Tian has come out with a conceptual framework to represent the centralized agri-food supply chain scenario as shown in Figure 2.6 (Tian, 2016). This centralized traceability system implements the information sharing and realizes the traceability management in the whole agri-food supply chain.

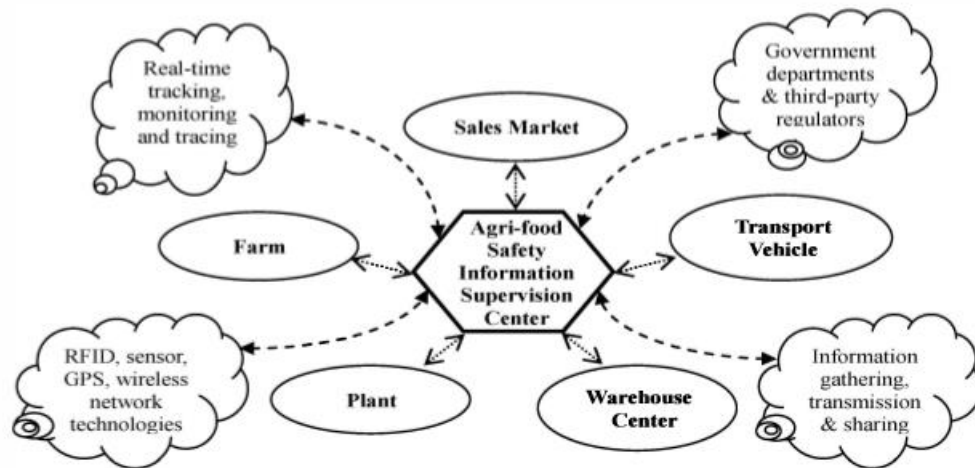


Figure 2.6: Conceptual framework of Centralized Agri-food Supply Chain Traceability System (Tian, 2016)

He points out that monopolistic, asymmetric, and opaque are the biggest problem of this centralized model which could result in issues of trust, such as falsifying information, corruption, fraud, and tampering.

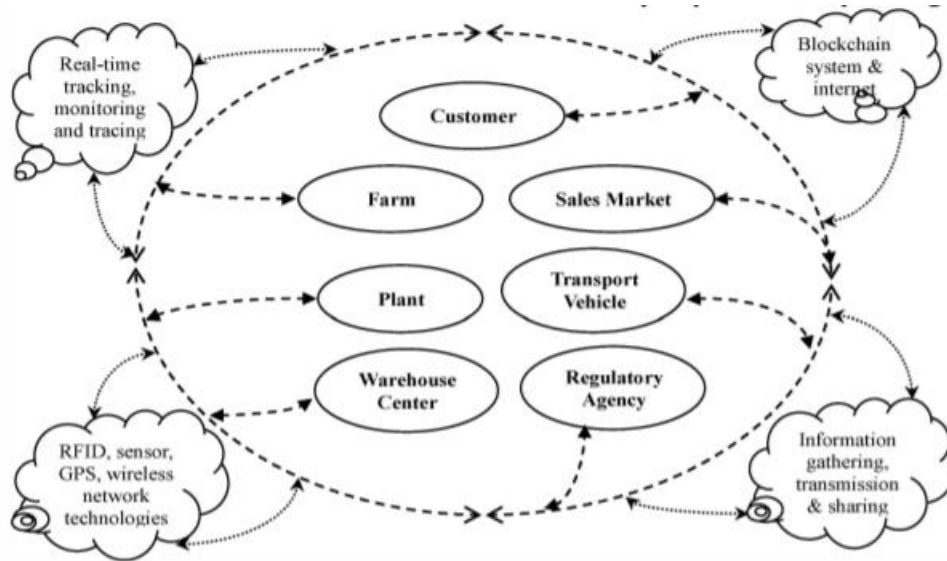


Figure 2.7: Conceptual Framework of Agri-food Supply Chain Traceability System based on RFID & Blockchain Technology (Tian, 2016)

The author is introducing a blockchain based supply chain model using Ethereum as depict in Figure 2.7 and proposing to use RFID and all sorts of sensor device for data acquisition purpose. It also emphasizes on the features of tracing and monitoring events with the help of blockchain and internet enabled systems. In financial standpoint, deployment of RFID might work on a smaller scale, but not so feasible in full scale. The solution is still in conceptual stage that without any technical implementation and more like evaluating the applicability of blockchain in supply chain

2.4.2 Modelling Food Supply Chain Traceability using Blockchain

Traceability is a critical element in modern supply chain management particularly in food sector where most people demand food safety. However, food supply chain is getting more and more complex and fragmented, this fragmentation become a huge barrier to develop a sound traceability system in current supply chain management (Casino, Kanakaris, Dasaklis, Moschuris, & Rachaniotis, 2019). Current food supply chain management is

adopting IoT applications and device in the effort of digitizing information to be control and quarried in real time. However, the reliability of the information with this system is questionable as the supply chain of a product involve too many participants and the supply chain network is too complex. There also have the probability that traceability information available is not consistent to all the participants as each of them might have different traceability mechanism (Casino, Kanakaris, Dasaklis, Moschuris, & Rachaniotis, 2019). This could possess significant risk as regulator authority in the supply chain network rely highly on the accuracy of information obtained to examine the food safety and provide certification.

Function	Input	Output	Permissions	Description
constructor	-	True/False	W ¹	Initializes and stores information about the order
addProduct	productName, productQuantity, description	True/False	W	Adds a product to the order list
getNumberOfProducts	-	Integer	W, D ² , R ³	Returns the number of products of the order

Figure 2.8: Food Supply Chain Model using Blockchain

Figure 2.8 shows a glimpse of a model that proposed by the author using blockchain (Ethereum) to provide a decentralized and automated traceability of food supply chain as shown in Figure 2.8. However, the model is too simple to truly represent the food supply chain scenario in real life. It consists of basic functions such as constructor, add product and so on. Then it determines each of the function required input and expected output. The permissions are to determine which function is available to whom, “W” is wholesaler, “D” is distributor and “R” is retailer.

	Performance metric	Estimate
Efficiency	Cost	High
	Automation	High
Responsiveness	Customer complaints	Medium
	Response times	Medium
Food quality	Process quality	High
	Product quality	High
Trust	Accountability	High
	Immutability	High
	Verifiability	High
	Data transparency	High

Figure 2.9: Key Performance Index

The author also presents a set of Key Performance Index (KPI) to determine the performance of the model base on efficiency, responsiveness, food quality and trust. However, the performance metric is only come with three level scale, which is low, medium, and high. These set of assessment also seems like only works on particularly the author design model as it does not present the step or procedure of the assessment and the three level scale should be in a more quantitative approach like percentage to provide a better insight.

2.4.3 Blockchain in Pharmaceutical Supply Chain

Bocek, Rodrigues, Strasser, and Stiller (2017) present a study on pharmaceutical supply chain by adopting blockchain technology, called Modum. The architecture of Modum consists of Ethereum Virtual Machine (EVM), Smart Contract, database, server, mobile devices, and sensors.

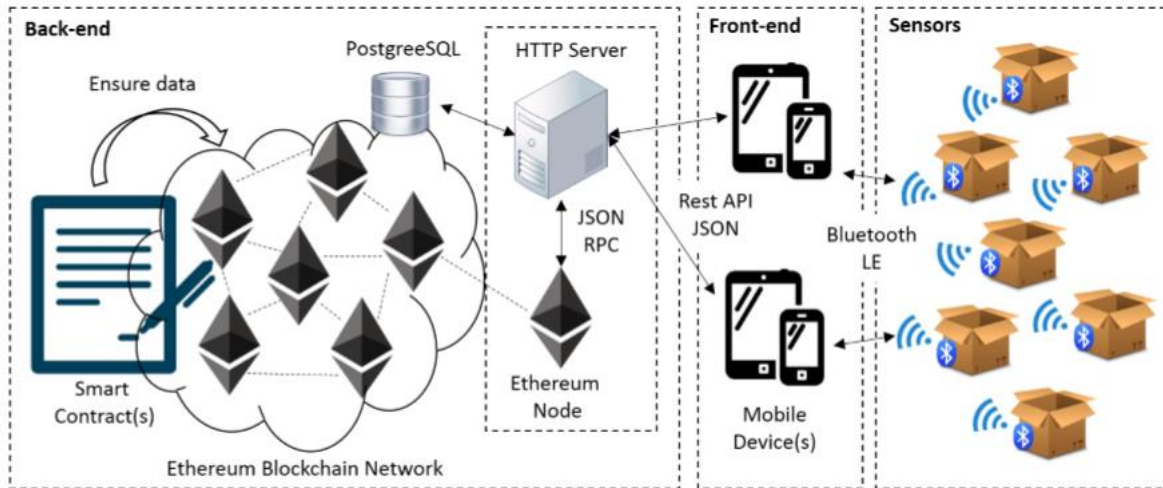


Figure 2.10: Architecture of Modum (Bocek, Rodrigues, Strasser, & Stiller, 2017)

Figure 2.8 illustrates how the architecture interact with each other components. The blockchain network is powered by EVM for running smart contracts and data registration. As Modum is designed for pharm supply chain, it emphasizes on the credibility and accuracy of data of temperature. The registered data will be stored in PostgreSQL, a relational database management system. Each of the node is connected to the database via JSON API. Modum is implemented in Android mobile devices in this study that can communicate with Bluetooth sensors and backend via JSON API. The authors have completed a prototype and conducted a pilot project and completed a total of 55 shipments. While it is impressive with such achievements, the studies do not present noticeable findings on supply chain transparency and traceability.

2.4.4 Ontology Based Design on Supply Chain using Blockchain

Provenance is one of the popular terms in blockchain related research, not only in supply chain industry but others as well. Kim and Laskowski (2016) are deduce that concept of ontology can complement to provenance with the aid of blockchain technology. In their

research, they design a data model that is ontology based and traceable. Before going in depth into the subject. There is a need to introduce the term Traceable Resource Unit (TRU), which is a unit that represent a batch of item that is traceable. The authors then develop a blockchain based supply chain solution using Ethereum framework and combining the ontology-based data model. In the assessment of the solution, it is successfully proved that it can trace the TRU of an item to its source of historical data, in other words provenance. The solution is proven with strong traceability but does not mentioned much about the transparency side of supply chain.

2.4.5 Existing Work vs Current Study

Table 2.3 is giving a summary on how the existing works compare with this study.

Table 2.3: Existing Work vs Current Study

Existing Work / Current Study	Nature of Blockchain Solution	Evaluation on the solution
RFID and Blockchain Based Supply Chain System	Public (Ethereum)	Evaluate the solution in terms of traceability and transparency qualitatively.
Modelling Food Supply Chain Traceability using Blockchain	Public (Ethereum)	Provide KPI to evaluate the solution certain criteria in three level scale, low, medium, and high only.

Table 2.3 continued

Blockchain in Pharmaceutical Supply Chain	Public (Ethereum)	Evaluate the solution in terms of traceability and transparency qualitatively.
Ontology based Design on Supply Chain using Blockchain	Public (Ethereum)	Evaluate the solution in traceability qualitatively only.
Current Study	Private (Hyperledger Fabric and Sawtooth)	Provide a quantitative metric on the evaluation in both blockchain solution in both traceability and transparency.

The evaluation in most solution is providing a qualitative approach either in terms of traceability or transparency, some did in both. Qualitative approach is referring to those researches is implementing the blockchain solution and merely describing the improvement of transparency and traceability in words, unlike current study is showing actual metrics in transparency and traceability. On the other hand, most of the solution is implementing only one kind of blockchain solution, where current study is implementing two blockchain framework.

2.5 On Time in Full (OTIF)

According to Meng and Qian (2018), On Time in Full (OTIF) is the most widely used metric for performance evaluation on supply chain deliveries. The formula of OTIF is presented as below:

$$OTIF = \frac{\text{number of deliveries}}{\text{total number of deliveries}} \times 100\% \quad \text{Equation 2.1}$$

It is a percentage value that serve the purpose of key performance index (KPI) of a supply chain in an organization. It is a simple yet effective assessment model for measuring the effectiveness of supply chain. The formula is easily explained as calculate the percentage of the number of goods delivered from organization A to organization B and divide by the total number of goods that organization A should deliver. The authors claim that OTIF is designed as post-production metric, it only can evaluate the delivery performance at the end of delivery. With basis of OTIF, it is then will be further modified as performances metric to evaluate the solution.

2.6 Summary

This chapter first describe the current supply chain scenario of pepper industry. It contains 5 main parties in the order of farmer, processor, distributor, retailer, and consumer. Before continuing to introduction of supply chain transparency and traceability, the metric that currently used to evaluate the performance of supply chain, On Time in Full (OTIF) is discussed. The difference of public and private blockchain is dissected in terms of governance, consensus, and the nature of network of each blockchain. Further in-depth explanation of private blockchain is carried out among Hyperledger Fabric and Sawtooth on their similarities and differences. A list of consensus algorithms is explained in terms of their

behaviour and the blockchain framework it supports. This chapter end with a detailed review of previous work, some of the most related work is discussed to highlight a sense of higher clarity of significance of this study compare to those related work. Most of the solutions use public blockchain (i.e. Ethereum) solution that are permissionless, meaning ledger is visible to non-relevant party. Some other solution is just merely determining the feasibility or potential on applying blockchain technology on supply chain rather than providing a usable solution for supply chain management.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Introduction

This chapter mainly discuss the methodology and research activities that are necessary for implementing the proposed solution. Methodology describes how the research questions that raised previously and how to turn it into proposed solution. This chapter begin with some assumptions that have been made on the current supply chain scenario of pepper industry in Malaysia. As supply chain and logistics management is complex and difficult to illustrate in a whole, these assumptions are aiding the representation of the supply chain scenario in a simplified manner. A flowchart has been used to present the research activities that have been carried out to accomplish the research objective from the beginning of this research. The last part of this section will end with the detailed description of the design of proposed solution and the evaluation method that will be carried from the results of implementation in the next chapter.

3.2 Assumptions

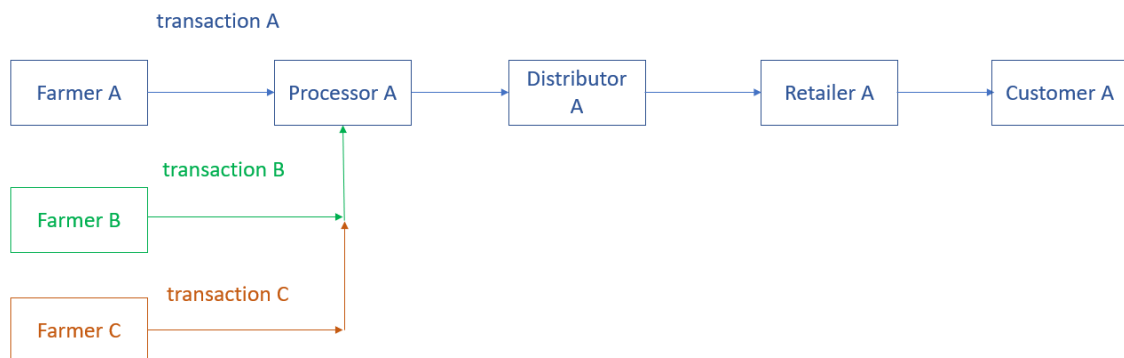


Figure 3.1: 3 Farmer Actors in the Supply Chain Network

There some assumptions have been made on setting the pepper supply chain scenario. It consists of 5 parties like the illustration of Figure 3.1 and without any sub party. For the purpose of evaluation of proposed solution in this study, there will be 3 actors of farmer in each supply chain stage. The setting of 3 farmers will have 3 different supply chain scenarios:

- i. Farmer A, Farmer B and Farmer C all have a transaction made with Processor A.
- ii. Farmer B and Farmer C have a transaction made with Processor A.
- iii. Only Farmer C made a transaction with Processor A.

This demonstration intends to find out how will it affect the transparency and traceability when more parties come in to the blockchain based supply chain network.

The proposed solution will apply Hyperledger Fabric and Sawtooth technology. First, both of this blockchain framework is private blockchain. Second, although both are private blockchain but the architecture design of both blockchains are different, which might affect the transparency and traceability in supply chain scenario as stated at section 3.2.

This study will apply the knowledge findings on supply chain transparency and traceability from previous chapter for evaluation and combine with the OTIF concept that is famously used in supply chain industry on formulating a performance indicator.

3.3 Proposed Framework

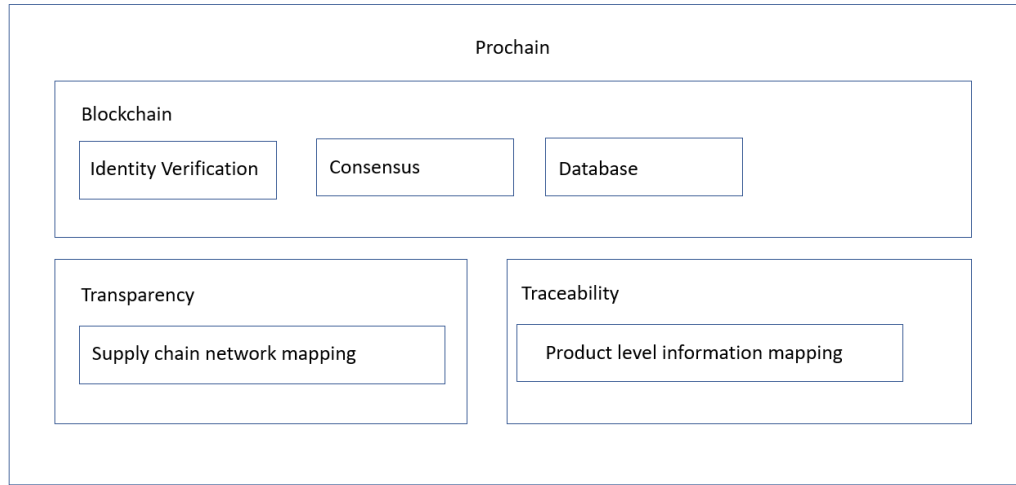


Figure 3.2: Overview of Proposed Framework

The proposed framework will be given a code name “Prochain”. Prochain is a traceable and transparent supply chain system that build on top of blockchain that will cover the whole process of data management, such as data input, sharing and data monitoring of every activity in the supply chain network. Prochain allow these verified parties to have write access to create a transaction with each other and gain read access for the information whenever they need. Prochain is illustrated in Figure 3.2.

Transparency and traceability here are define as supply chain mapping and product level information mapping respectively. Both of them will be quantified base on these definitions using OTIF, it will then be used as performance indicator for the implemented blockchain framework. Note that blockchain based supply chain solution is part of Prochain, these two indicators are part of fulfilling the Prochain framework as shown in Figure 3.2.

3.3.1 Blockchain

The supply chain management comprise of a supply chain system using blockchain and all the relevant parties (i.e. farmer, processor, distributor, retailer, and consumer) in the

supply chain that joined in the network. Regardless the differences in private blockchain technology there consists of three basic building blocks, which are identify verification, consensus, and database.

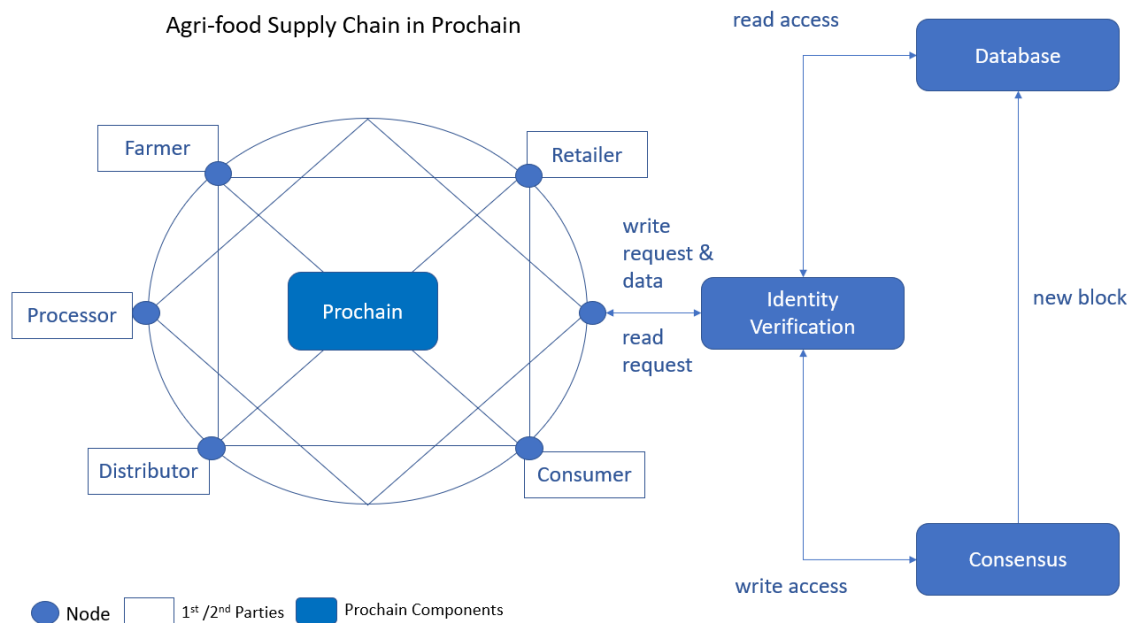


Figure 3.3: Illustration of Conceptual Framework of Agri-food Supply Chain in Prochain

Prochain consists of identity verification, consensus algorithm and database. Prochain will first assign a digital certificate to each of the party that are to be invited to join the supply chain network, this means that all the party in Figure 3.3 like farmer, processor, distributor, retailer will be issued a digital certificate to each of them. It is required for identity verification whenever they need to have write access to create transaction to other party. Prochain could allow second party to join the network if the party within the blockchain network agreed. Second party could be transportation company, or warehouse company to gain read access to the transaction date they need to carry on the operations.

3.3.1.1 Transaction Flow of Prochain between Farmer and Processor

In order to make the transactions happens, the transaction data captured by Prochain will undergo a consensus algorithm before appends the new transaction (block) to the supply chain network (chain). The prerequisite is Prochain will verify the identity of the current user, whether they have the access of read, write or both.

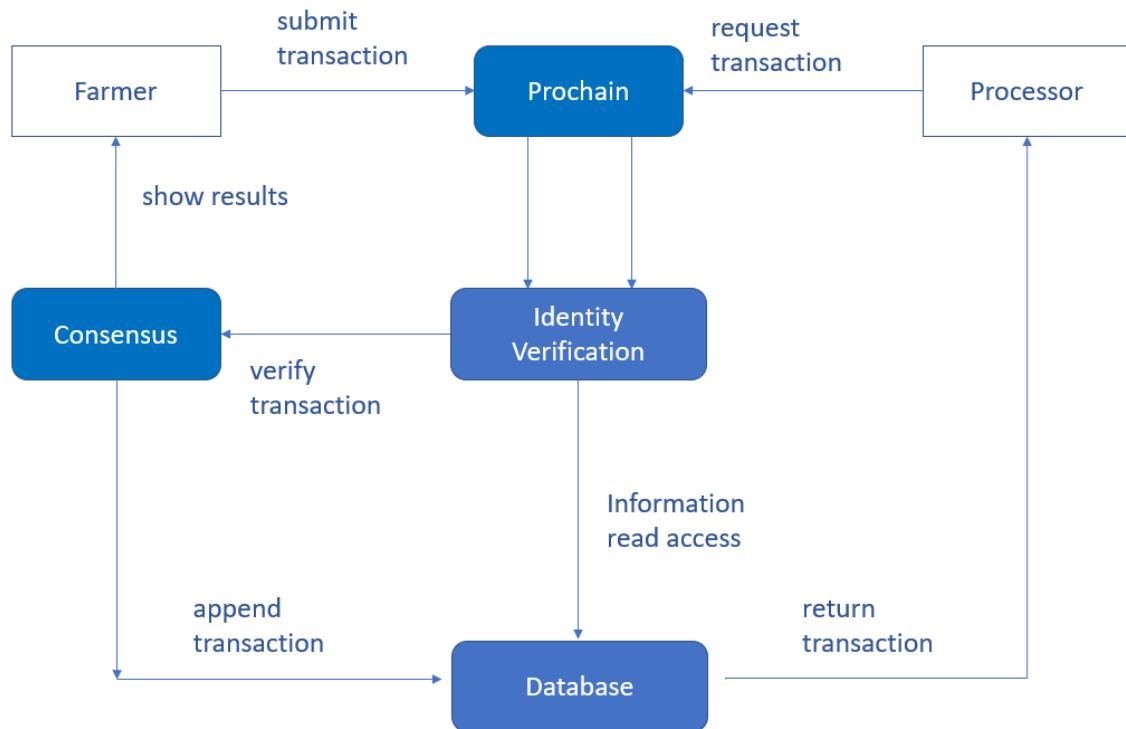


Figure 3.4: Transaction flow between Farmer and Processor

From Figure 3.4, farmer will submit a transaction request to be append to the blockchain database. Prochain will authenticate the farmer before allowing the transaction data undergo consensus algorithm. Once the transaction data is signed after consensus algorithm, it will append to the blockchain database, and Prochain will notify and show the results to farmer. Processor who is also in the same blockchain network, will query the transaction information when in need. They will still need to be authenticated before access the transaction data.

This basically describe how a general blockchain based supply chain system is functioning in Prochain framework. During implementation stage, Hyperledger Fabric and Sawtooth both will be applied into this framework and will utilized the assessment model that will be described later for analysis.

On the other hand, Figure 3.5 depicts how is the parties in the supply chain manage the transactional data with each other via trusted third party. In a centralized supply chain system, all the information is revolving from supply chain parties to the third-party layer service providers.

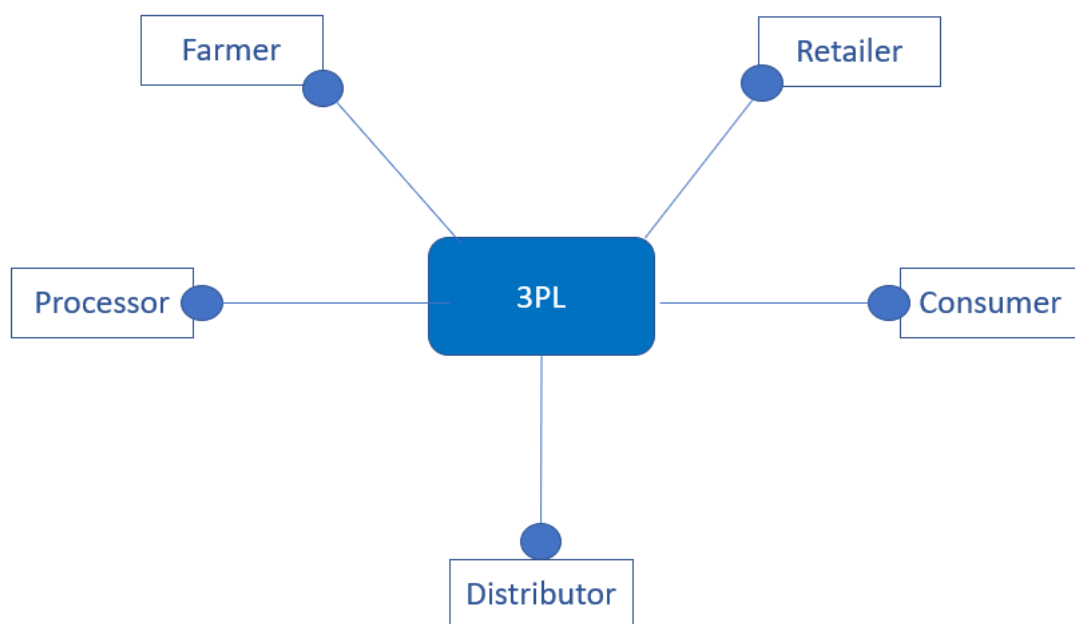


Figure 3.5: Conceptual Framework for Centralized Supply Chain System

Looking back the transaction flow of Prochain, none of the transaction has undergo to non-relevant party. The data in the blockchain is signed and encrypted before appending to the blockchain database to ensure the credibility of the data. All the transaction flow is

transparent among supply chain parties. the transparency of Prochain, the traceability of the system will work as it should be.

3.3.1.2 Consumer

Consumer is a special party in Prochain. The way they gain the read access of a product can be in several ways, i.e. QR code, barcode, and RFID tag. It is up to the retailer or other relevant party who sold the product to them on how they want to disclose the information of a product to consumer. Hence, consumer does not need to authenticate identity to get the product information.

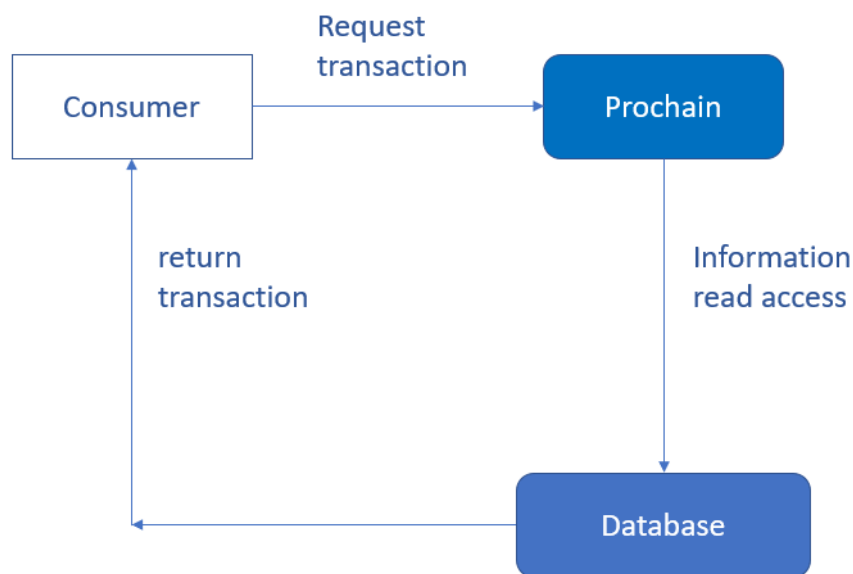


Figure 3.6: Read Access of Consumer

Base on Figure 3.6, consumer request a transaction information in many ways such as via QR code, barcode or RFID tag that will generate query through Prochain application. There is no identity authentication in the process and transaction result will straight away present to consumer.

3.3.2 Transparency and Traceability

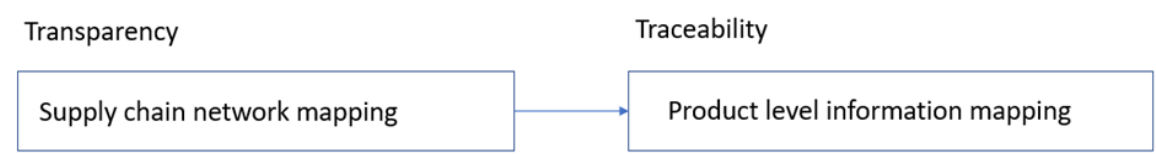


Figure 3.7: Transparency and Traceability

Base on the facts that mentioned in Section 2.2, supply chain transparency is about providing information of supply chain party, hence mapping the whole supply chain network. Supply chain traceability is about providing information on product level and mapping the flow of product from the source. The relationship of supply chain transparency and traceability can be described as traceability is dependent on transparency, higher transparency will be able to provide higher intensity of traceability as shown in Figure 3.7.

3.4 Data Input

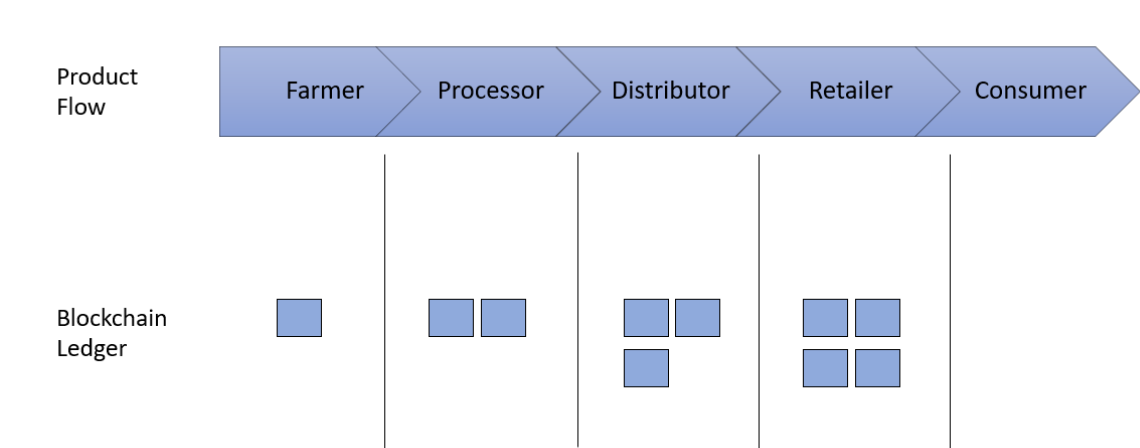


Figure 3.8: Flow of Product and Blockchain Ledger

Figure 3.8 (extended from Figure 2.1) illustrates a simple representation of the food supply system and its main phases. As the flow of product went further, more and more ledger will be appended to the blockchain system as there will be new information generated every time the product is transfer to a new owner.

Table 3.1 provides some insight on the data that is populated for experimental study in the framework. These data are populated by collectively referring to various source of dataset as it resemblance the supply chain data that exist in most food supply chain (Willems, 2017; United Nation, 2018, Food and Agriculture Organization of the United Nations, 2017). The data is populated until the stage before consumer, this is due to the consumer is assigned with read access in the supply chain network as presented in Figure 3.6. Note that in real implementation there will be much more technical data and meta data generated by the system, this table provides a glimpse on supply chain relevant data that is required when creating new transaction or product transfer from one owner to another. Some data like location and datetime seems repetitive however it is necessary in the process as at each stage of supply change these data needed to be updated accordingly and not overwriting the previous data value. It is required as part of the backtracking process. Note that both Sawtooth and Fabric will be using the same data.

Table 3.1: Data of Blockchain Ledger

Farmer	Processor	Distributor	Retailer/ Wholesaler
Owner Name	Owner Name	Owner Name	Owner Name
Location	Location	Location	Location
Created DateTime	Created DateTime	Created DateTime	Created DateTime
Custodian	Custodian	Custodian	Custodian
	Updated DateTime	Updated DateTime	Updated DateTime
Species	Temperature	Temperature	Temperature
Weight	Pack No.	Pack No.	Pack No.
Temperature	Price Per Pack	Price Per Pack	Price Per Pack
Price	Box No.	Box No.	Box No.
	Quantity	Quantity	Quantity

Each of the table contain the at least 5 transparency data (as highlighted in red). This information is defined as transparency data that consist of Name, Location, DateTime, Person in charge and Owner Name. Name is representing an entity, be it an individual, company or organization that is currently who own the current ledger by creating one itself or transferred from other party accompanying with Location and DateTime of this ledger when created or transferred. Custodian is the actor that in charge of approving and accepting the ledger from another party. The rest of the data (which are not highlighted) will be categorised as traceability data, that will provide much more granularity information of a

product (pepper), such as species, weight, temperature and price (at the stage of farmer). Since the ledger is append-only, the existing data is not needed to be recorded again when it is transfer to another owner, as the previous information is remained in the database. However certain information could be changed over time such as price per pack. Price per pack is different when transfer from Processor to Distributor and Distributor to retailer, same goes to other information like Pack No., Box No., and Quantity.

3.5 Assessment on Transparency and Traceability

By applying the performance metric of OTIF as mentioned in Section 2.7, it enabled the transparency and traceability of supply chain quantifiable and more importantly measurable. Base on the formula of OTIF, supply chain transparency and traceability can be formulated as:

$$\begin{aligned} & \text{Supply Chain Transparency} && \text{Equation 3.1} \\ &= \frac{\text{Supplier Information obtained}}{\text{Total Information of Supplier}} \times 100\% \end{aligned}$$

$$\begin{aligned} & \text{Supply Chain Traceability} && \text{Equation 3.2} \\ &= \frac{\text{Product Information obtained}}{\text{Total Information of Product}} \times 100\% \end{aligned}$$

With these two performance indicators complementing Prochain framework, it will be used as analysis of transparency and traceability of both Fabric and Sawtooth version of blockchain based supply chain system.

This section will explain on how the OTIF based metric of Transparency and Traceability will be applied as illustrated in Figure 3.8. Both implementation of Sawtooth and Fabric will be applied with the same data input and allow each of the stakeholder in the network to query information of the ledger. Hence, based on the information obtained via

querying from the system. Transparency and traceability are defined as Equation 3.1 and Equation 3.2 respectively, the information obtained is used to calculated with metric of transparency and traceability. This process will undergo at each stage of supply chain. For instance, such assessment will be made when there is a transaction occur from farmer to processor, or processor to distributor and so on.

The assessment will involve 3 supply chain scenarios. First scenario is there is only one party in each of the stage of supply chain, i.e. 1 farmer, 1 processor, 1 distributor, 1 retailer, or 1 consumer. The second scenario is there will be 2 farmers instead of 1, and the rest of the supply chain stage remain 1 party. The reason to remain 1 party for the rest of it instead of making it 2, is the study intend to find out how is the slightest increase amount of supply chain party affect the whole supply chain transparency and traceability. Third scenario is where third farmer added to the blockchain network.

This study will have 3 kind of results as stated as below:

1. Comparison of Transparency and Traceability of Sawtooth and Fabric at First Stage of all the three scenarios. Instead of presenting the assessment into three individually, it will be present in one because as first stage of supply chain data is not too many and can be easily combine both into one.
2. Comparison of Transparency of Sawtooth and Fabric with all the three scenarios.
3. Comparison of Traceability of Sawtooth and Fabric with all the three scenarios.

3.6 Summary

This chapter highlighted the research methodology applied from formulation of research problem into proposed solutions. Before that, a few important assumptions have been made that shaped to the design of solution, Prochain. Prochain consist of three main pillar which are blockchain based supply chain system, supply chain transparency and traceability. The flow of process of blockchain based supply chain system is described in detail from the perspective of various stakeholders. The last part of Prochain which is the assessment model is also constructed by quantifying and formulating transparency and traceability which will be uses intensively in the next chapter.

CHAPTER 4

IMPLEMENTATION AND ANALYSIS

4.1 Introduction

This chapter will evaluate both version of Prochain which are Hyperledger Fabric and Hyperledger Sawtooth based on the transparency and traceability. The first step will be populating the data that will be used for experimental purpose for both frameworks. Next analysis of transparency and traceability will be carried out and compare with each other respectively.

4.2 Prochain Hyperledger Sawtooth Version

This version of Prochain will be called as Prochain Sawtooth. This section will discuss the main things which is the technical specification that require in implementing Prochain Sawtooth. The implementation is then explained in detail on how a transaction happened in the system accompanying with screenshot of the system.

4.2.1 Technical Specifications of Prochain using Hyperledger Sawtooth

All the technical requirements and specifications of Hyperledger Sawtooth are presented in Table 4.1. Each of the versioning of specification is stated clearly while implementing Hyperledger Sawtooth in Prochain. These specifications are being deployed as it is being suggested as stable release by the official developer documentation at that time.

Table 4.1: Technical Specifications of Prochain Hyperledger Sawtooth Version

Requirements & Specifications	Version
Node.js	v6.9 or later
Ubuntu	16.04 or later
npm package manager	3.x or later
Golang	v1.8 or later
Docker	17.03.1-ce or later
Docker Compose	1.9.0 or later
Hyperledger Sawtooth Docker Images and Binaries	1.1.0 or later

4.2.2 Applying Hyperledger Sawtooth into Prochain

Base on the transaction flow of conceptual framework as shown in Figure 3.4 which depicts the general blockchain component interact with each other when a transaction is made. Figure 4.1 presents a specific version of Prochain with Hyperledger Sawtooth blockchain applied.

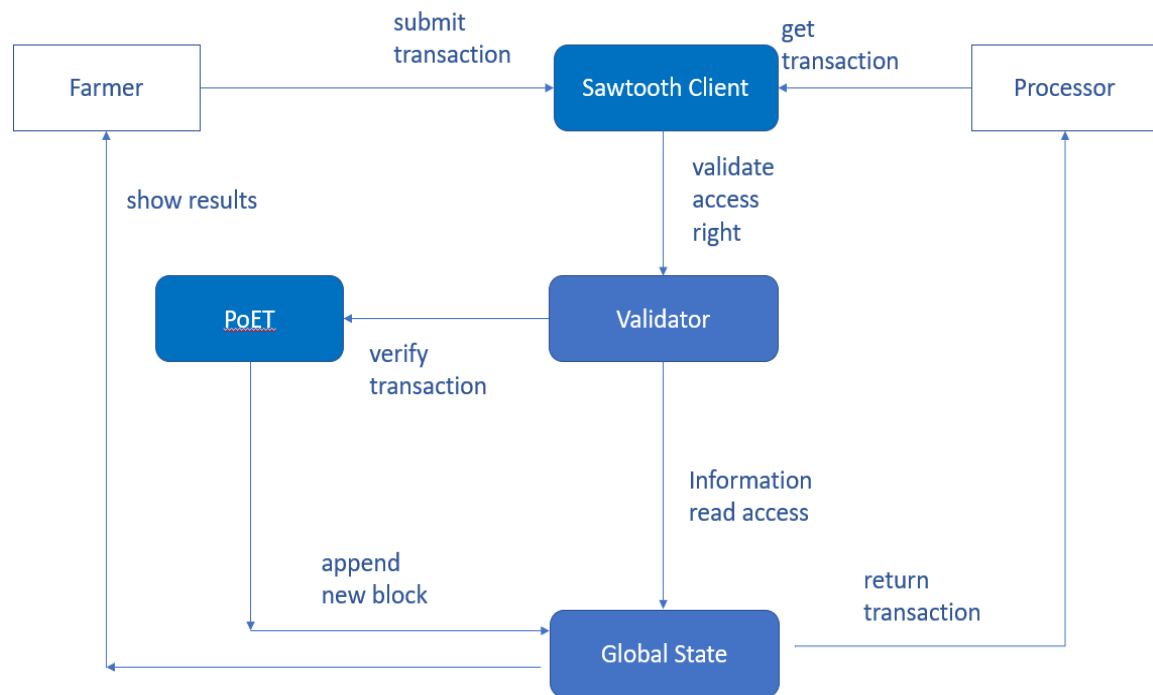


Figure 4.1: Prochain Hyperledger Sawtooth Version

Base on Figure 4.1, farmer or processor can have read-write access via the Sawtooth client. Either one of the access will first notify the validator in the blockchain network. The validator will first examine the access right of the user, if the user is doing a transaction submission, the validator will communicate with the transaction processor which is the backend service of Sawtooth, if the transaction is valid it will undergo the PoET consensus for the creation of the new block.

Waiting time is randomly assigning to all the nodes (validators) that in charge of validating the transaction, regardless of the power or type of hardware of that node possesses. Then the validator with the shortest wait time will have to append the new block and update the global state, which is the database that consists of all and the latest record of the ledger and being shared across all nodes of that blockchain network.

4.2.3 Implementation of Prochain Sawtooth System

Prochain Sawtooth consists of various component that build on Docker and on Ubuntu. Components of Prochain Sawtooth include, client application, validator, and database; each of them is implemented as a separate docker component. Each of this docker component is encapsulated into a single docker-compose file. The client application is implemented with a web app interface that is accessible at localhost:8000 once all the instances of container are up and running.

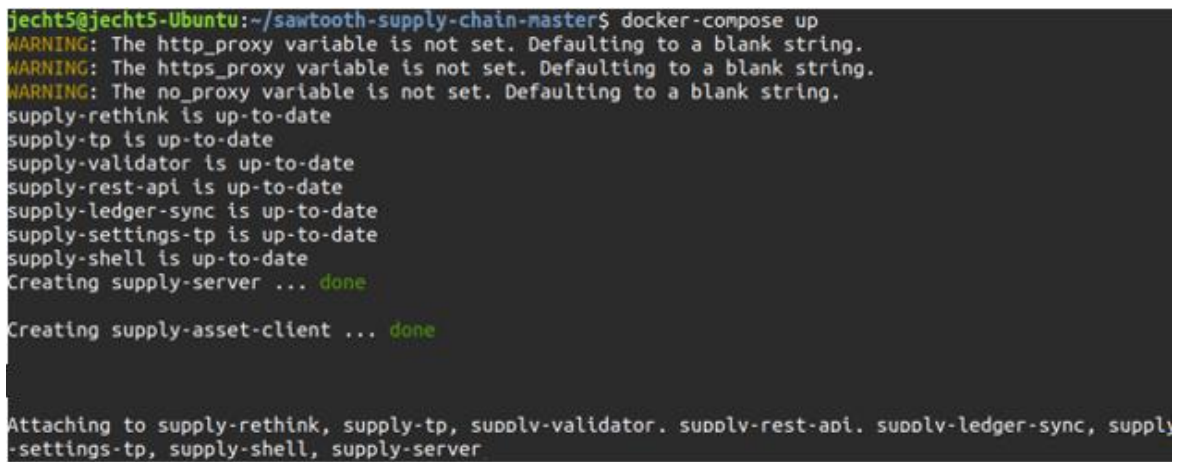
A terminal window screenshot showing the execution of the 'docker-compose up' command. The prompt is 'jecht5@jecht5-Ubuntu:~/sawtooth-supply-chain-master\$'. The output shows several warnings about proxy variables and then a list of components being checked for updates: 'supply-rethink is up-to-date', 'supply-tp is up-to-date', 'supply-validator is up-to-date', 'supply-rest-api is up-to-date', 'supply-ledger-sync is up-to-date', 'supply-settings-tp is up-to-date', and 'supply-shell is up-to-date'. Then, 'Creating supply-server ... done' and 'Creating supply-asset-client ... done' are shown. Finally, it says 'Attaching to supply-rethink, supply-tp, supply-validator, supply-rest-api, supply-ledger-sync, supply-settings-tp, supply-shell, supply-server'.

Figure 4.2: Initiate Prochain Sawtooth via Bash CLI

Figure 4.2 shows that Prochain Sawtooth can be easily initiated using a single “docker-compose up” command to create an instance of all the docker component, which consists of supply-rethink, supply-tp, supply-validator, supply-rest-api, supply-ledger-sync, supply-settings-tp, supply-shell, and supply-server. Once the command is entered, it will first confirm the version of every docker component are up to date. Once the instance is created successfully, it will start running the process and each docker component is assigned with different colour in the command line when it is in processing as show in Figure 4.3.

```
supply-server | Retrying database in 5 seconds...
supply-ladger-type | Database not initialized: supply_chain
supply-ladger-type | Retrying database in 5 seconds...
supply-shell | Creating "blocks" table...
supply-shell | Bootstrapping complete, closing connection.
supply-shell | > supply_chain_server@0.0.0 make-asset /sawtooth-supply-chain/server
supply-shell | > DATA"/.../asset_client/sample_data/core_types.json" node ./scripts/seed_core_types.js
supply-shell | Server unavailable, retrying in 5 seconds...
supply-server | Successfully connected to database: supply_chain
supply-server | Supply Chain Server listening on port 3000
supply-ladger-type | Successfully connected to database: supply_chain
supply-ladger-type | Connected to tcp://validator:4004
supply-validator | [2020-01-06 01:24:45.448 DEBUG broadcaster] Added Subscriber 71107b6ad50f2b39b83c3e3c6d657a70c10ea4e1ac1b075df41a1d5097afe69bc560cde38303c42367a4a93c4
c709426ebc64306244ca736381f040bf17f3c4 for [<sawtooth_validator.server.events.subscription.EventSubscription object at 0x7fc4a9cb5da0>, <sawtooth_validator.server.events.su
scription.EventSubscription object at 0x7fc4a9cb5da0>]
supply-validator | [2020-01-06 01:24:45.441 DEBUG broadcaster] Catching up Subscriber 71107b6ad50f2b39b83c3e3c6d657a70c10ea4e1ac1b075df41a1d5097afe69bc560cde38303c42367a
a93c4dc709426ebc64306244ca736381f040bf17f3c4 from 00000000000000000000
supply-validator | [2020-01-06 01:24:45.442 WARNING broadcaster] Transaction id f9df353343 not found in receipt store while looking up events for block id 23046ad901
supply-server | Received GET request for /info from ::ffff:172.18.0.8
supply-server | Received POST request for /transactions?wait from ::ffff:172.18.0.8
supply-tp | INFO | sawtooth_sdk::proces | Message: 78a5c149bed54fff7b1b0e19fb2a4944a
supply-tp | INFO | supply_chain.tp::han | payload: CreateAgent(name: "Supply Chain Admin") 1578273888 3400de 3400de
supply-tp | INFO | sawtooth_sdk::proces | TP_PROCESS_REQUEST sending TpProcessResponse: OK
supply-tp | INFO | sawtooth_sdk::proces | Message: 11fb8fe8f4b646dd8e6f156171c8341a
supply-tp | INFO | supply_chain.tp::han | payload: CreateRecordType(name: "asset" properties (name: "type" data_type: STRING required: true) properties (name: "subty
e" data_type: STRING) properties (name: "weight" data_type: NUMBER number_exponent: -6) properties (name: "shock" data_type: NUMBER number_exponent: -6) properties (name: "location" data_type: LOCATION) properties (name: "temperature" da
a_type: NUMBER number_exponent: -6) properties (name: "shock" data_type: NUMBER number_exponent: -6) 1578273888 3400de 3400de
supply-tp | INFO | sawtooth_sdk::proces | TP_PROCESS_REQUEST sending TpProcessResponse: OK
supply-validator | [2020-01-06 01:24:45.428 INFO publisher] Claimed Block: b24668d7b49f4770497a6126ecd27baf4b06e5b7c8087e1679974c32ec41bae85e264ce5821a471758513b015237b
1562260d7357dc94aa9e990ddc5c7f8a54 (block_num:1, state:1a42f0c61234b9def625f402cb49adafbac2af827e2d117b5e3b7cab782193ac6, previous_block_id:23046ad90179b4a9b7bf0900c844c7b18
98fbb3d7f156fc724bc718f633634950d3da3e18b8985df9cb812bfaba88e9d91f4480a2a55b3af5233eda53806d57)
supply-validator | [2020-01-06 01:24:48.424 INFO publisher] Block publishing is suspended until new chain head arrives.
supply-validator | [2020-01-06 01:24:48.426 DEBUG chain] Block received: b24668d7b49f4770497a6126ecd27baf4b06e5b7c8087e1679974c32ec41bae85e264ce5821a471758513b015237be15
```

Figure 4.3: Docker Component Initiated

Create Agent

Name

Email

Username

Password

WARNING!

This password will be used as a secret key to encrypt important account information. Although it can be changed later, if lost or forgotten it will be impossible to recover your account.

Keep it secure.

Enter password...

Confirm password...

Or you can [login an existing Agent](#)

Create Agent

Figure 4.4: Prochain Sawtooth - Registration and Login

The Prochain Sawtooth is designed to let stakeholder do the registration themselves in the system as shown in Figure 4.4. Once registration is done, stakeholder then can create new transaction or accept transaction from other party. The information needed for the registration is simple, Name, Email, Username and Password. A private key will be generated to each participants of the Prochain Sawtooth network, this private key is required whenever to create new transaction and accept transaction ledger.

Prochain

Add TransactionView TransactionView Stakeholder

ProfileLogout

New Transaction

Serial Number

001

Species

Black Pepper

Price

55000

Weight (kg)

1000

Latitude

1.5533

Longitude

110.3592

Authorize Reporters

Add reporter by name or public key...

Select Fields ▼

Create Record

Figure 4.5: Prochain Sawtooth - Add New Record

Figure 4.5 shows the interface of creating new transaction record in Prochain Sawtooth (from Farmer to Processor). The information required are Serial Number (input manually), Species (of the pepper), Price, Weight (the total weight of pepper) and Location (Latitude and Longitude). Authorized Reporter is optional input field that depends on the farmer would like to assign any participant from the network to examine validity of data. Some information is autogenerated such as Created DateTime and Updated DateTime. Both of this data have the same value from the beginning, but value of Created DateTime will remain the same once transaction is being accepted, and Updated DateTime will have a new entry whenever a transaction is being updated or transfer to another owner.

Prochain Add Transaction View Transaction View Stakeholder					Profile Logout
All Owned Custodian Reporting					
Serial Number	Species	Added	Updated	Updates	
002	White Pepper	01/05/2020, 9:13:10 pm	01/05/2020, 9:13:10 pm	4	
001	Black Pepper	01/05/2020, 9:07:39 pm	01/05/2020, 9:07:39 pm	4	

Figure 4.6: Prochain Sawtooth - View All Records

Figure 4.6 shows the interface of viewing historical record of transaction that have been made. Prochain Sawtooth remain all the information accessible to all stakeholders in the supply chain network. The information of ledger presented here are Serial Number, Species, Created DateTime, Updated DateTime. The record here can be categorized into three categories, which are Owned, Custodian and Reporting. These three words are reflecting Owner, Custodian and Reporter. Owner is referring to the current owner of this ledger, but the item of the ledger might not in possession by the owner. Custodian do not necessarily own the item of ledger but can temporarily in possession of the item, who probably oversee transportation and other similar position. Owner and Custodian can be same person in this case is farmer2 as shown in Figure 4.7. Else, Owner can appoint another person to become Custodian who probably are representative from company that in charge of transportation, logistic or any other entity that Owner (farmer2) relinquish the right of the ledger temporarily to handle certain task. Reporter is an actor that is optionally assigned by the Owner to represent owner on updating the ledger information or authority who will examine validity of item and have read access to update information of the item but never own or possess the item. In this case Owner (farmer2) handle all the related task himself hence no Reporter is shown.

Prochain
Add Transaction
View Transaction
View Stakeholder
Profile
Logout

002

Created
2020-01-05
Owner
farmer2
Custodian
farmer2
Species
White Pepper
Price
50000000000
Location
1.5533, 110.3592
Temperature
Unknown
Package
N/A
Box
N/A

Updated
2020-01-05
Transfer Ownership
Transfer Custodianship
Weight (kg)
1000
LatitudeLongitudeUpdate
Temperature (C°)Update
Pack No.Price Per PackUpdate
Box No.Quantity Per BoxUpdate

Figure 4.7: Sawtooth – View Record Details

Figure 4.7 presents the interface of viewing details of a particular transaction. The previous information of transaction details such as DateCreated, Owner, Custodian, Species, Price, Location are immutable. As the item will be transfer to another owner, there are some information that can be further updated or appended which are new Location, Temperature (temperature is crucial on pepper), Package (packaging information, pack number and price per pack), and Box (further packing information, box number and total amount of packs of product in one box). Note that making update on the ledger not necessarily in the process of transferring ownership, current owner can also update the information in certain circumstances. For instance, the current owner is the processor itself that need to update the information of current price before transferring to next owner.

002

Created
2020-01-05

Owner
farmer2

Custodian
farmer2

Species
White Pepper

Price
50000000000

Location
1.5533, 110.3592

Temperature
Unknown

Updated
2020-01-05

Transfer Ownership ▼

Transfer Custodianship ▼

retailer1
farmer1
transport1
Supply Chain Admin
distributor1
processor1
Supply Chain Admin

Longitude

Update

Update

Figure 4.8: Transfer Ownership and Custodianship

Figure 4.8 illustrates how the ownership of a ledger can be transfer to another owner. When the current owner press on Transfer Ownership dropdown button, a list of participants who currently in the network will appear and can be transfer to anyone of them. The same situation applies to transferring custodianship, any participants in the Prochain Sawtooth network can become custodian of that item.

Prochain Add Transaction View Transaction View Stakeholder Profile Logout					
All	Owners	Custodians	Reporters		
Name	Key	Owns	Custodian	Reports	
Supply Chain Admin	0306021192efe82ca2ac56e027897...	0	0	0	
Supply Chain Admin	033003f3a5c24a518dc8b117ae64d...	0	0	0	
distributor1	0362e551c94c43d876839e240d41c...	0	0	0	
farmer1	0372aaabee6291e099a4e3b649146...	1	1	1	
farmer2	0344dc54faf791e7ba83787788eed...	1	1	1	
processor1	0314c414691a065f01fe1b56593d5...	0	0	0	
retailer1	03e1242fe0c2c96e736bd4885776b...	0	0	0	
transport1	0396050b07e9b2e9982388d2f2bf2...	0	0	0	

Figure 4.9: Sawtooth – View Stakeholders

Figure 4.9 shows the lists of stakeholders that who involved in this transaction from the beginning until latest record. Note that it also shows the information of private key of a participant as it is required and obtainable when assigning one of the participants as reporter of a ledger.

4.3 Prochain Hyperledger Fabric Version

This version of Prochain will be called as Prochain Fabric. This section will discuss three main things which is the technical specification that require in implementing Prochain Fabric. The implementation is then explained in detail on how a transaction happened in the system. These specifications are being deployed as it is being suggested as stable release by the official developer documentation at that time

4.3.1 Technical Specifications of Prochain using Hyperledger Fabric

Table 4.2: Technical Specifications of Prochain Hyperledger Fabric Version

Requirements & Specifications	Version
Node.js	v6.9 or later
Ubuntu	16.04 or later
npm package manager	3.x or later
Golang	v1.8 or later
Docker	17.03.1-ce or later
Docker Compose	1.9.0 or later
Hyperledger Fabric Docker Images and Binaries	1.1.0 or later

All the technical requirements and specifications of Hyperledger Fabric are presented in Table 4.2. Each of the versioning of specification is stated clearly while implementing Hyperledger Fabric in Prochain.

4.3.2 Applying Hyperledger Fabric into Prochain

These are all the requirements that need to be met for development of Prochain using Fabric. The key component consists of client application, membership service provider, endorsing peer, committing peer, ordering service, channel, and state database. The relationships of these component are depicted in Figure 4.10. Client application is a node in the blockchain network that allow user to write or read information. Every client application is preinstalled with membership service provider for purpose of defines the rules in which identities are validated, authenticated, and allowed access to a network. The Membership Service Provider (MSP) manages user IDs and authenticates clients who want to join the network. This includes providing credentials for these clients to propose transactions. The MSP makes use of a Certificate Authority, which is a pluggable interface that verifies and revokes user certificates upon confirmed identity. The default interface used for the MSP is the Fabric-CA API, however, organizations can implement an External Certificate Authority of their choice.

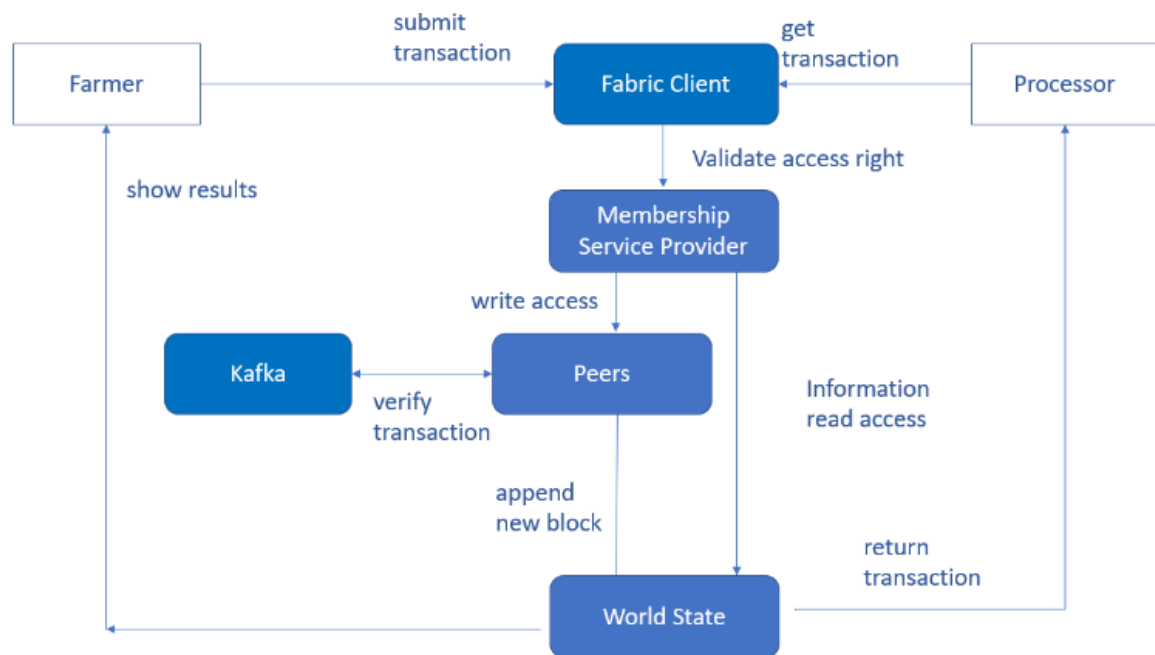


Figure 4.10: Prochain Hyperledger Fabric Version

Base on Figure 4.10, the user can have read write access via Fabric Client. The MSP will validate the access right of the user. If the user is submitting a transaction it will pass to peers and undergo Kafka consensus algorithm before appending the new block. A much details visualization of the process is shown in Figure 4.11.

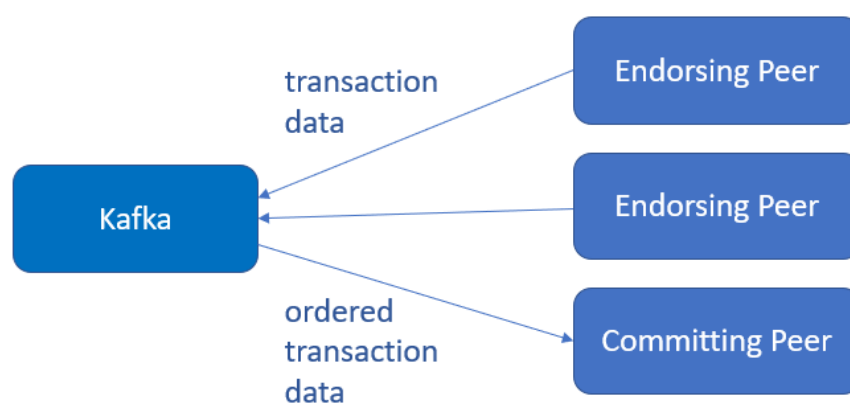


Figure 4.11: Transaction flow in Ordering Service

The Peers in Figure 4.11 consists of Endorsing Peer and Committing Peer. The role of Endorsing Peer is passing a set of transaction data that proposed by the user to be sorted under Kafka. There is a need of Kafka (an ordering mechanism) to sort out the set of transaction data then will pass to the Committing Peer that in charge of creating the new block into the World State. World state is a database that store all and the latest record of ledger that being shared across all nodes in that blockchain network. Peers can belong to multiple networks or channels. Peers that do participate in multiple channels simulate and commit transactions to different ledgers. The ordering service is the same across any network or channel.

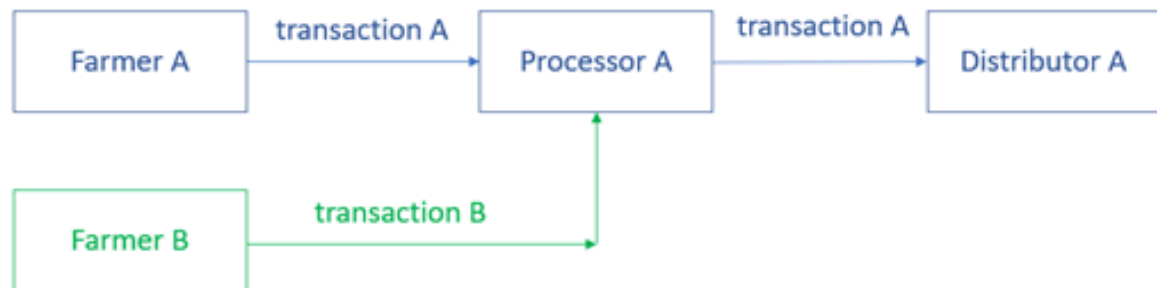


Figure 4.12: 2 Channels in the same Fabric blockchain network

However, transparency and traceability of Prochain are affected by the variation of the building block of Sawtooth and Fabric. As shown in Figure 4.12, one notable variation is the feature of Channel provided from Fabric that allows the stakeholders in the network to carry out transaction privately with a subset of other stakeholders that are not visible to another subset of stakeholders.

4.3.3 Implementation of Prochain Fabric System

Prochain Fabric System also consists of various docker component and even more than Prochain Sawtooth. The client application consists of a web app interface that is accessible at localhost:8000 once all the instance of container is up and running.

```
basic-network > ! configtx.yaml

1  OrgsOrdererGenesis:
2      Orderer:
3          <<: *OrdererDefaults
4          Organizations:
5              - *OrdererOrg
6      Consortiums:
7          PepperConsortium:
8              Organizations:
9                  - *Farmer1
10                 - *Farmer2
11                 - *Farmer3
12                 - *Processor1
13                 - *Distributor1
14                 - *Retailer1
```

Figure 4.13: configtx file – All Organizations

The Prochain Fabric consists of a file named as configtx that is used to define the number of channels that is desired under a Prochain Fabric network and the Organization in this network. Organization here is a general term that refers to the participants in the network. In this study, the Organization consists of 3 farmers, 1 processor, 1 distributor and 1 retailer as shown in Figure 4.13. As mention in Section 3.5 about the reason of 3 supply chain scenarios being demonstrated, each supply chain scenarios are represented by 1 channel, hence there are going to be 3 channels being configured.

```

15 OrgsChannel1:
16   Consortium: PepperConsortium
17   Application:
18     <<: *ApplicationDefaults
19     Organizations:
20       - *Farmer1
21       - *Farmer2
22       - *Farmer3
23       - *Processor1
24       - *Distributor1
25       - *Retailer1
26
27 OrgsChannel2:
28   Consortium: PepperConsortium
29   Application:
30     <<: *ApplicationDefaults
31     Organizations:
32       - *Farmer2
33       - *Farmer3
34       - *Processor1
35       - *Distributor1
36       - *Retailer1
37
38 OrgsChannel3:
39   Consortium: PepperConsortium
40   Application:
41     <<: *ApplicationDefaults
42     Organizations:
43       - *Farmer3
44       - *Processor1
45       - *Distributor1
46       - *Retailer1
47

```

Figure 4.14: configtx file – Configure 3 Channels

Configtx file can further define the number of Channels in the Prochain Fabric network. Figure 4.14 shows that 3 Channels have been created. First Channel (Line 15 - 25 in Figure 4.14) consists of all the participants. Second Channel (Line 27 - 36 in Figure 4.14) does not include Farmer1 and third channel (Line 38 - 46 in Figure 4.14) does not include Farmer1 and Farmer2. All the participants will be defined here and automatically validate by MSP upon Prochain Fabric is initiated in Bash CLI, hence there is no registration and login require.

```

jecht5@jecht5-Ubuntu:~/education/LFS171x/fabric-material/tuna-app$ ./startFabric.sh

# don't rewrite paths for Windows Git Bash users
export MSYS_NO_PATHCONV=1

docker-compose -f docker-compose.yml down
Stopping cli ... done
Stopping peer0.org1.example.com ... done
Stopping ca.example.com ... done
Stopping couchdb ... done
Stopping orderer.example.com ... done
Removing cli ... done
Removing peer0.org1.example.com ... done
Removing ca.example.com ... done
Removing couchdb ... done
Removing orderer.example.com ... done
Removing network net_basic

docker-compose -f docker-compose.yml up -d ca.example.com orderer.example.com peer0.org1.example.com couchdb
Creating network "net_basic" with the default driver
Creating couchdb ... done
Creating orderer.example.com ... done
Creating ca.example.com ... done
Creating peer0.org1.example.com ... done

# wait for Hyperledger Fabric to start
# incase of errors when running later commands, issue export FABRIC_START_TIMEOUT=<larger number>
export FABRIC_START_TIMEOUT=10
#echo ${FABRIC_START_TIMEOUT}
sleep ${FABRIC_START_TIMEOUT}

# Create the channel
docker exec -e "CORE_PEER_LOCALMSPID=Org1MSP" -e "CORE_PEER_MSPCONFIGPATH=/etc/hyperledger/msp/users/Admin@org1.example.com/m
sp" peer0.org1.example.com peer channel create -o orderer.example.com:7050 -c mychannel -f /etc/hyperledger/configtx/channel.
tx

```

Figure 4.15: Initiate Prochain Fabric

The command to initiate Prochain Fabric is slightly different than Prochain Sawtooth, it uses “./startFabric.sh”, which is actually a name of the file that consist of all the docker command which include “docker-compose up” command to invoke all docker components. Another different process here is Prochain Fabric is programmed to remove all the existing instance of docker container in the system before creating and run their own docker container process.

Prochain Fabric

Query All Transaction

Query

ID	DateTime	Owner	Location (Longitude, Latitude)	Species
001	15/7/2020	Farmer2	1.4115° N, 111.5290° E	Black Pepper
002	15/7/2020	Farmer2	1.4115° N, 111.5290° E	White Pepper
003	15/7/2020	Processor1	1.5535° N, 110.3593° E	Black Pepper
004	16/7/2020	Farmer3	4.3995° N, 113.9914° E	Black Pepper
005	17/7/2020	Distributor1	3.1713° N, 113.0419° E	Black Pepper
006	17/7/2020	Retailer1	1.9951° N, 112.9331° E	Black Pepper

Figure 4.16: Query All Transactions

Figure 4.16 shows the interface that allows a user to query information of all transactions which include ID, DateTime, Owner, Location and Species.

Query a Specific Transaction

Enter Serial No:

Ex: 3

Query

DateTime	Owner	Location (Longitude, Latitude)	Species
15/7/2020	Processor1	1.5535° N, 110.3593° E	Black Pepper

Figure 4.17: Query a Specific Transactions

As the list of transaction will keep on increasing, it will be much more convenient for user to query a particular transaction information with the ID as shown in Figure 4.17.

Create New Transaction

Serial Number:

Species:

Longitude:

Latitude:

DateTime:

Owner:

Create

Figure 4.18: Create New Transaction

Change Owner

Enter Serial No.:

Enter New Owner:

Change

Figure 4.19: Change Owner

Any user can create new transaction (as shown in in Figure 4.18) and transferable to other participants in the same Channels (as shown in Figure 4.19).

4.4 Analysis of Prochain Sawtooth and Prochain Fabric

Although the consensus algorithm of Hyperledger Sawtooth and Hyperledger Fabric are not the same, it does not have any impact on the transparency nor the traceability of Prochain, as it just affects the procedure of the creation of the new block.

4.4.1 Transparency and Traceability at First Stage of Supply

As mentioned in Section 3.5, the assessment of Transparency and Traceability at First Stage of Supply Chain (from Farmer to Processor) will be combining into one instead of having two separately due to the data size is not large and easily illustrate in one table. Hence, the both the Equation 3.1 and Equation 3.2 will be combined into one equation just for this case.

Figure 4.12 shows the data of transaction A is visible to Farmer A, Processor A and Distributor A as all of them are on the same channel. However, the data of transaction B is only visible among Farmer B and Processor A but not Farmer A and Distributor A, note that both channels co-exist in the same blockchain network.

Base on the steps of finding the supply chain transparency and traceability in Section 3.4, a subset of data of suppliers (Farmer and Processor) and transaction data (pepper) is disclosed as shown in Figure 4.20. Both the Sawtooth and Fabric version of Prochain is using the same data in the analysis.

Farmer Name	}	Suppliers Data (Transparency)
Farm Location		
Farm DateTime		
Processor Name		
Processor Location		
Processor DateTime		
Box No.	}	Transactions data (Traceability)
Next Location		
Truck Driver		
Person in charge		
Pepper Berries Color		
Pepper Tree		
Price		

Figure 4.20: Suppliers and Transactions data from Farmer to Processor

Table 4.3: Transparency and Traceability at First Stage of Supply Chain

Prochain	Transparency and Traceability (%)
Sawtooth	$\frac{39}{39} \times 100\% = 100$
Fabric (1 channel)	$\frac{39}{39} \times 100\% = 100$
Fabric (2 channels)	$\frac{26}{39} \times 100\% = 67$
Fabric (3 channels)	$\frac{13}{39} \times 100\% = 33$

The first stage of supply chain (from Farmer to Processor in the supply chain network) is involving Farmer1, Farmer2 and Farmer3 create and transfer transaction to Processor, respectively. In other words, the data is recorded from Farmer1 to Distributor, Farmer2 to Distributor, and Farmer3 to Distributor. By applying the performance indicator of transparency and traceability established in Section 3.4.2, the OTIF applied transparency and traceability can be illustrated as shown in Table 4.3. Table 4.3 shows that Sawtooth can achieve 100 percent transparency and traceability whereas Fabric is a little bit more complicated. In the same channel of stakeholders, it can have the same results as Sawtooth, but stakeholder that is out of that channel has zero visibility of the data.

The total number of data transact from a farmer to a processor is 13 as shown in Figure 4.20, 6 is transparency data and 7 is traceability data. Hence, in Sawtooth and Fabric (1 Channel) have 39 data in total as there are three farmers in the supply chain network. Note

that Sawtooth does not have the channel feature like Fabric, hence transaction of all Farmer1, Farmer2 and Farmer3 is visible to each other, and Fabric (1 Channel) basically behave the same as Sawtooth. This is because every participant in Sawtooth and Fabric (1 Channel) has the same read access throughout all information in the Prochain system. In Fabric with 2 Channels, only two third of the information is available since Farmer1 is excluded. In Fabric with 3 Channels, only one third of information remain available as only Farmer3 transaction information is available.

4.4.2 Overall Supply Chain Transparency

Table 4.4 shows the result of overall Supply Chain Transparency. At the first stage (farmer to processor) of result, there are a total of 24 data. Starting from second stage (processor to distributor) there have increment of 15 data which include new location and updated DateTime, the increment of data is same to the third stage of supply chain (distributor to retailer). Until the final stage of supply chain (retailer to consumer), where retailer does not create any more data and will only present the data that they have hence the amount of data remain the same (54). The same situation applies to Fabric with 1 channel.

Fabric with 2 channels and 3 channels shows degradation of transparency at first stage. In Fabric with 2 channels, there are 1 farmer that is not included which means that the second channel has only two third of the visibility of data, hence only 16 data from 24. In Fabric with 3 channels, there are 2 farmers that are not included which means the third channel only have one third (8) of the visibility of the total data (24). Although the overall transparency percentage is the same across each stage of supply chain, but the amount of transparency data is increasing as data input is increasing and losing at the same rate.

Table 4.4: Overall Supply Chain Transparency

Prochain	Supply Chain Transparency (%)			
	Farmer to Processor	Processor to Distributor	Distributor to Retailer	Retailer to Consumer
Sawtooth	$\frac{24}{24} \times 100\%$ = 100	$\frac{39}{39} \times 100\%$ = 100	$\frac{54}{54} \times 100\%$ = 100	$\frac{54}{54} \times 100\%$ = 100
Fabric (1 channel)	$\frac{24}{24} \times 100\%$ = 100	$\frac{39}{39} \times 100\%$ = 100	$\frac{54}{54} \times 100\%$ = 100	$\frac{54}{54} \times 100\%$ = 100
Fabric (2 channels)	$\frac{16}{24} \times 100\%$ = 67	$\frac{26}{39} \times 100\%$ = 67	$\frac{36}{54} \times 100\%$ = 67	$\frac{36}{54} \times 100\%$ = 67
Fabric (3 channels)	$\frac{8}{24} \times 100\%$ = 33	$\frac{13}{39} \times 100\%$ = 33	$\frac{18}{54} \times 100\%$ = 33	$\frac{18}{54} \times 100\%$ = 33

	Farmer1 to Processor1	Processor1 to Distributor1	Distributor1 to Retailer1
	Owner Name	Owner Name	Owner Name
	Location	Location	Location
	Created DateTime	Created DateTime	Created DateTime
	Custodian	Custodian	Custodian
	Reporter	Updated DateTime	Updated DateTime
	Company Name		
	Company Location		
	Company Type		
Number of data	8	5	5
	Farmer2 to Processor1	Processor1 to Distributor1	Distributor1 to Retailer1
	Owner Name	Owner Name	Owner Name
	Location	Location	Location
	Created DateTime	Created DateTime	Created DateTime
	Custodian	Custodian	Custodian
	Reporter	Updated DateTime	Updated DateTime
	Company Name		
	Company Location		
	Company Type		
Number of data	8	5	5
	Farmer3 to Processor1	Processor1 to Distributor1	Distributor1 to Retailer1
	Owner Name	Owner Name	Owner Name
	Location	Location	Location
	Created DateTime	Created DateTime	Created DateTime
	Custodian	Custodian	Custodian
	Reporter	Updated DateTime	Updated DateTime
	Company Name		
	Company Location		
	Company Type		
Number of data	8	5	5
Increment of data	24	15	15
Total number of data	24	39	54

Figure 4.21: Supply Chain Transparency of Prochain Sawtooth

Figure 4.21 shows how is the first row (Sawtooth) of value obtained in Table 4.4. The number of data obtained from Farmer1 to Processor1 is 8. As there are three farmers in the supply chain scenario, the total number of data obtained from Farmer to Processor is 24. This also applies to the rest of the supply chain transparency and traceability.

4.4.3 Overall Supply Chain Traceability

Table 4.5: Overall Supply Chain Traceability

Prochain	Supply Chain Traceability (%)			
	Farmer to Processor	Processor to Distributor	Distributor to Retailer	Retailer to Consumer
Sawtooth	$\frac{42}{42} \times 100\%$ = 100	$\frac{63}{63} \times 100\%$ = 100	$\frac{84}{84} \times 100\%$ = 100	$\frac{84}{84} \times 100\%$ = 100
Fabric (one channel)	$\frac{42}{42} \times 100\%$ = 100	$\frac{63}{63} \times 100\%$ = 100	$\frac{84}{84} \times 100\%$ = 100	$\frac{84}{84} \times 100\%$ = 100
Fabric (2 channels)	$\frac{28}{42} \times 100\%$ = 67	$\frac{42}{63} \times 100\%$ = 67	$\frac{56}{84} \times 100\%$ = 67	$\frac{56}{84} \times 100\%$ = 67
Fabric (3 channels)	$\frac{14}{42} \times 100\%$ = 33	$\frac{21}{63} \times 100\%$ = 33	$\frac{28}{84} \times 100\%$ = 33	$\frac{28}{84} \times 100\%$ = 33

Table 4.5 shows the result of overall Supply Chain Traceability. At the first stage (farmer to processor) of result, there are a total of 42 data. Starting from second stage (processor to distributor) there have increment of 21 data which include new price and packaging information, the increment of data is same to the third stage of supply chain (distributor to retailer). Until the final stage (retailer to consumer), where retailer does not create any more data and will only present the data that they have hence the amount of data remain the same (84). The same situation applies to Fabric with 1 channel.

Fabric with 2 channels and 3 channels shows degradation of transparency at first stage. In Fabric with 2 channels, there are 1 farmer which is not included which means that the second channel have only two third of the visibility of data, hence only 28 data from 42. In Fabric with 3 channels, there are 2 farmers which are not included which means the third channel only have one third (14) of the visibility of the total data (42). Although the overall traceability percentage is same across each stage of supply chain, but the amount of traceability data is increasing as data input is increasing and losing at the same rate. Also note that the overall amount of data of traceability is more than transparency data due to granularity of information of a product compare to transparency data that only consist information about stakeholders.

4.5 Summary

This chapter mainly discuss about discussing the implementation and analysis of Prochain Sawtooth and Prochain Fabric. First, the technical requirements and specification of both frameworks has been listed out clearly before the implementation takes place. Then implementation of both frameworks is discussed step by step on how the flow of transaction works in the supply chain network on each framework given that both have their own differences. The analysis section is utilizing the OTIF applied transparency and traceability as the performance indicator on determining the supply chain transparency and traceability in both framework and the results is illustrated into tables with explanation. Overall Sawtooth has proved great transparency and traceability, but in real world adoption, there are certain stakeholder might prefer Fabric simply because the feature of channel is able to maintain certain level of anonymity for competitive advantage.

CHAPTER 5

CONCLUSION AND FUTURE WORKS

5.1 Introduction

Blockchain has been gaining lots of hype around, and one of the most promising application is supply chain, various research has been carried out about this topic. Earlier studies mostly focus on the applicability and readiness of blockchain technology into supply chain field. Most of these studies prove that blockchain has wide range of positive impact on supply chain, but also facing certain challenges that indicating blockchain based solution is not ready for adoption for real business.

On the other hand, there is a huge benefit that current status quo of blockchain technology is able to deliver, which is the promise of transparency and traceability and remove the needs of participation of third party as shown in this study. Razzaq et al. (2019) mentioned that blockchain is capable to remove the centralized third party by distributing control away from the central authorities in business, communication, law or even politics.

5.2 Achievements

Both private blockchain Hyperledger Sawtooth and Hyperledger Fabric version of Prochain implemented into the supply chain use case in pepper industry. These implementation and analysis show that the aim of this research which is to design and develop a blockchain based framework that consist of transparency and traceability for supply chain management of agri-food sector (specifically in pepper sector) in Malaysia has achieved successfully.

In response to the blockchain technology that is most suitable apply to Prochain, the conclusion is not so direct as both Sawtooth and Fabric has different things to offer. Without

a doubt this study proves that Sawtooth possess higher degree of supply chain transparency which lead to higher traceability, some stakeholders might prefer the feature of Channel that possessed by Fabric to remain anonymity of certain information. Ideally, implementation of Sawtooth is more beneficial to end user as higher transparency will boost the confidence of them to the product. A little suggestion here is all the stakeholders achieve a consensus on the anonymity or clarity of information to disclose before implement the rules into smart contract of blockchain, hence the benefit of all stakeholders is taken care of.

Prochain also successfully achieved the objective of evaluating the transparency and traceability of each of the blockchain technology. With the formulation of supply chain transparency and traceability metric that derive from OTIF, and base on the definition of supply chain transparency and traceability introduced by Tsai (2018); both Sawtooth and Fabric has been successfully assessed.

5.3 Significance of Contributions

The motivation of this study is to explore how blockchain technology will affect the transparency and traceability of supply chain. Since blockchain is gaining lots of hype, there are quite a lot of studies has been carried out related to blockchain before this study. The notable contribution in this study is findings on supply chain transparency and traceability.

Before carrying out this study, blockchain has already well known on providing a better transparency of removing the participation of third party and partly due to their nature of immutability of data. However, Tsai (2018) has provided a higher clarity on term of transparency and traceability in supply chain. Rather than merely implement blockchain technology in to supply chain system and describe how blockchain improve transparency and traceability in a quantitative approach; this study adopts a metric for transparency and traceability base on OTIF and being utilized in Prochain.

5.4 Future Works

After what this study has accomplished, there are still some room of improvement that can further enhance in Prochain. First, Prochain shall carry out assessment other Blockchain framework. This study has implemented the blockchain base supply chain system using Hyperledger Sawtooth and Fabric. In the literature review mentioned other blockchain framework is still at infancy stage. However, in the future those blockchain framework should also be evaluated in transparency and traceability metric as shown in this study to find out which framework is best to be adopted on production, possibly to look into hybrid blockchain as well. Second, the metric of transparency and traceability should be review from time to time as there might be a better basis for it other than OTIF.

Although the technicality analysis of the blockchain framework is not a focus on this study, however in supply chain, there are some non-functional analysis that is beneficial to carry out. For example, the scalability and performance of the blockchain framework. As the supply chain network could keep on growing, it is important to find out on which extend of the blockchain network can scale to meet the demand. It is worthwhile to mention that the importance of performance is on par with scalability such as speed of a transaction generation.

5.5 Summary

Blockchain is applicable on a very wide field of computing, it has so much potential that is yet to explore but there are some challenges that the blockchain is hurdling the rate of adoption of blockchain. The key for the fast adoption rate of blockchain highly dependent on Blockchain eliminated the needed of “trust” among third party, however until today even high profile private blockchain framework such as Hyperledger is still being seen as immature tech and it require a very big initiative for a company to adopt it as companies has

invested tremendous amount of financial and human resource into the current supply chain solution.

The industry still needs many more successful stories to be convinced on fully adopting blockchain. It is convincing enough to say this research has brought meaningful insight to the stakeholders who are interested on adopting blockchain in supply chain in near future. Companies should note that this can be a huge gain for them as a competitive advantage. A company can market themselves utilizing blockchain that guarantee the transparency of a product sources, which can greatly boost customer confidence to the product and the brand of the company itself.

REFERENCES

- Akerlof, G. A. (1970). The market for “Lemons”: Quality uncertainty and the market mechanism. *Quarterly Journal of Economics*, 84(3), 488-500.
- Alkhodre, A., Jan, S., Khusro, S., Ali, T., Alsaawy, Y., & Yasar, M. (2019). A Blockchain-based Value Added Tax (VAT) System: Saudi Arabia as a Use-Case. *International Journal of Advanced Computer Science and Applications*, 10(5), 708-716.
- Aung, M. M., & Chang, Y. S. (2014). Traceability in a food supply chain: Safety and quality perspectives. *Food Control*, 39, 172-184.
- Bambrough, B. (2019, September 18). *What Is Going On With Bitcoin Rival Stellar?*
Retrieved from Forbes:
<https://www.forbes.com/sites/billybambrough/2019/09/18/what-is-going-on-with-bitcoin-rival-stellar/#6da230a63d25>
- Bateman, A., & Bonanni, L. (2019). *What Supply Chain Transparency Really Means*.
Retrieved from Havard Business Review: <https://hbr.org/2019/08/what-supply-chain-transparency-really-means>
- Bocek, T., Rodrigues, B. B., Strasser, T., & Stiller, B. (2017). Blockchains everywhere - a use-case of blockchains in the pharma supply-chain. *2017 IFIP/IEEE Symposium on Integrated Network and Service Management (IM)* (pp. 772-777). Lisbon: IEEE.
- Caro, M. P., Ali, M. S., Vecchio, M., & Giaffreda, R. (2018). Blockchain-based traceability in Agri-Food supply chain management: A practical implementation. *2018 IoT Vertical and Topical Summit on Agriculture - Tuscany (IOT Tuscany)* (pp. 1-4). Tuscany, Italy: IEEE.

- Casado-Vara, R., Prietoa, J., De La Prietaa, F., & Corchado, J. M. (2018). How blockchain improves the supply chain: case study alimentary supply chain. *Procedia Computer Science*, 134, 393-398.
- Casino, F., Kanakaris, V., Dasaklis, T., Moschuris, S., & Rachaniotis, N. (2019). Modeling Food Supply Chain Traceability based on Blockchain Technology. *IFAC-PapersOnLine*, 52(13), 2728-2733. doi:<https://doi.org/10.1016/j.ifacol.2019.11.620>
- Chetak Logistics. (2015). *Difference between 1PL, 2PL, 3PL, 4PL & 5PL*. Retrieved from <https://www.linkedin.com/pulse/difference-between-1pl-2pl-3pl-4pl-5pl-chetak-logistics/>
- Coyler, A. (2015). *Practical Byzantine Fault Tolerance*. Retrieved from <https://blog.acolyer.org/2015/05/18/practical-byzantine-fault-tolerance/>
- Deimel, M., Frentrup, M., & Theuvsen, L. (2008). Transparency in food supply chains: Empirical results from German pig and dairy production. *Journal on Chain and Network Science*, 8(1), 21-32.
- Doorey, D. J. (2011). The transparent supply chain: From resistance to implementation at Nike and Levi-Strauss. *Journal of Business Ethics*, 103(4), 587-603.
- Duong-Trung, N., Ha, X. S., Phan, T. T., Trieu, P. N., Nguyen, Q. N., Pham, D., . . . Le, H. T. (2019). Multi-sessions mechanism for decentralized cashon delivery system. *International Journal of Advanced Computer Science and Applications*, 10(9), 533-560.
- Egels-Zandén, N., & Hansson, N. (2016). Supply chain transparency as a consumer or corporate tool: The case of Nudie Jeans Co. *Journal of Consumer Policy*, 39(4), 377-395.

- Fletcher, N. (2017). *Illegal cross-border pepper, rubber farming uncovered*. Retrieved from
Retrieved from <http://www.theborneopost.com/2017/04/03/illegal-cross-border-pepper-rubber-farming-uncovered/>
- Food and Agriculture Organization of the United Nations. (2017). *Agriculture*. Retrieved from
Data.World : https://data.world/agriculture/crop-production/workspace/file?filename=Production_Crops_E_Asia.csv
- Gupta, M. (2017). *Blockchain For Dummies®*, IBM Limited Edition. Hoboken, NJ: John Wiley & Sons, Inc.
- Handfield, R. B., & Ernest, L. N. (2002). In *Supply Chain Redesign: Converting Your Supply Chain into an Integrated Value Stream*. New York: Financial Prentice Hall.
Retrieved from Handfield, R. B. & Ernest, L. N. Jr. (2002). *Supply Chain Redesign: Converting Your Supply Chain into an Integrated Value Stream*. Financial Prentice Hall, New York.
- Hayes, A. (2019, September 15). *Is Ethereum More Important Than Bitcoin?* Retrieved from
Investopedia: <https://www.investopedia.com/articles/investing/032216/ethereum-more-important-bitcoin.asp>
- Hofstedel, C. J., Schepers, H., Spaans-Dijkstra, L., Trienekens, J. H., & Beulens, A. J. (2004). *Hide or confide: the dilemma of transparency*. Netherlands: Reed Business Information.
- Hyperledger. (2018). *About Hyperledger*. Retrieved from Hyperledger :
<https://www.hyperledger.org/about>
- Jain, P. (2018). *The ABCs of Kafka in Hyperledger Fabric*. Retrieved from
<https://codeburst.io/the-abcs-of-kafka-in-hyperledger-fabric-81e6dc18da56>

- Kaptein, M., & Van Tulder, R. (2003). Toward effective stakeholder dialogue. *Business and Society Review*, 108(2), 203-224.
- Khan, A. S., Balan, K., Javed, Y., Tarmizi, S., & Abdullah, J. (2019). Secure Trust-Based Blockchain Architecture to Prevent Attacks in VANET. *Sensors*, 19(22), 4954.
- Kim, H. M., & Laskowski, M. (2018). Toward an ontology-driven blockchain design for supply-chain provenance. *Intelligent Systems in Accounting, Finance and Management*, 25(1), 18-27.
- Koo, A., Othman, A. L., Moy, P. Y., & Khor, P. (2017). *Agribusiness*. Retrieved from <https://gettingthedealthrough.com/area/93/jurisdiction/55/agribusiness-malaysia/>.
- Kumar, P. (2018). *Understanding Consensus Algorithm*. Retrieved from <https://medium.com/@pravindia/understanding-consensus-algorithm-ee73162f6c50>
- Laney, J. (2018). *How Blockchain can revolutionise the Supply Chain*. Retrieved from <https://jameslaney.com/blockchain-revolutionise-supply-chain/>
- Le, N. T., Nguyen, Q. N., Phien, N. N., Duong-Trung, N., Huynh, T. T., Nguyen, T. P., & Son, H. X. (2019). Assuring Non-fraudulent Transactions in Cash on Delivery by Introducing Double Smart Contracts. *International Journal of Advanced Computer Science and Applications*, 10(5), 677-684.
- Lee, H. H. (2013). *How a "3-D" supply chain process system could revolutionize business*. Retrieved from <http://www.supplychainquarterly.com/topics/Strategy/20130621-how-a-3-d-supply-chain-process-system-could-revolutionize-business/>
- Mah, S. K. (2017). *Bright future for Sarawak pepper*. Retrieved from Retrieved from <https://www.thestar.com.my/news/nation/2017/10/25/malaysia-aims-to-be-worlds-top-supplier-of-the-premium-king-of-spices/>

- Manzini, R., & Accorsi, R. (2013). The new conceptual framework for food supply chain assessment. *Journal of Food Engineering*, 115(2), 251-263.
- Meng, H., & Qian, Y. (2018). The Blockchain Application in Supply Chain Management: Opportunities, Challenges and Outlook. doi:<https://doi.org/10.29007/cv1j>
- Meng, M. H., & Qian, Y. (2018). A blockchain aided metric for predictive delivery performance in supply chain management. *2018 IEEE International Conference on Service Operations and Logistics and Informatics (SOLI)* (pp. 285-290). Singapore: IEEE.
- Nakamoto, S. (2008). *Bitcoin: A peer-to-peer electronic cash system*. Retrieved from <https://bitcoin.org/bitcoin.pdf>
- Neisse, R., Steri, G., & Nai-Fovino, I. (2019). A Blockchain-based Approach for Data Accountability and Provenance Tracking. *Telematics and Informatics*, 36, 55-81. doi:<https://doi.org/10.1016/j.tele.2018.11.006>
- Prasanna. (2019). *What is Ethereum Virtual Machine?* . Retrieved from CryptoTicker: <https://ethdocs.org/en/latest/introduction/what-is-ethereum.html>
- Randall, M. (2018). *Blockchain Consensus Algorithms: An Early Days Overview*. Retrieved from <https://medium.com/coinmonks/blockchain-consensus-algorithms-an-early-days-overview-2973f0cf49c6>
- Razzaq, A., Khan, M. M., Talib, R., Butt, A. D., Hanif, N., Afzal, S., & Raouf, M. R. (2019). Use of Blockchain in Governance: A Systematic Literature Review. *International Journal of Advanced Computer Science and Applications*, 10(5), 685-691.
- Richardson, M. (2017). *Ethereum vs Hyperledger*. Retrieved from Blockchain Training Alliance: <https://blockchaintrainingalliance.com/blogs/news/ethereum-vs-hyperledger>

- Rilee, K. (2018). *Understanding Hyperledger Fabric — Channel Lifecycle*. Retrieved from Medium: <https://medium.com/kokster/understanding-hyperledger-fabric-channel-lifecycle-a546670646e3>
- Stoica, I., Morris, R., Karger, D., Kaashoek, M., Dabek, F., & Balakrishnan, H. (2003). Chord: a scalable peer-to-peer lookup protocol for Internet applications. *IEEE/ACM Transactions on Networking*, 11(1), 17 - 32.
- Surasak, T., Wattanavichean, N., Preuksakarn, C., & Huang, S. C. (2019). Thai agriculture products traceability system using blockchain and internet of things. *International Journal of Advanced Computer Science and Applications*, 10(9), 578-583.
- Swan, M. (2015). *Blockchain: Blueprint for a New Economy*. CA: O'Reilly Media.
- Tapscott, D., & Ticoll, D. (2003). *The naked corporation: How the age of transparency will revolutionize business*. New York: Simon and Schuster.
- Tian, F. (2016). An agri-food supply chain traceability system for China based on RFID & blockchain technology. *2016 13th international conference on service systems and service management (ICSSSM)* (pp. 1-6). Kunming: IEEE.
- Tsai, K. (2018). *Transparency vs. Traceability: What's the Difference?* Retrieved from <https://www.transparency-one.com/transparency-vs-traceability-whats-the-difference/>
- United Nations. (2018). *Global Food & Agriculture Statistics*. Retrieved from Kaggle: https://www.kaggle.com/unitednations/global-food-agriculture-statistics?select=fao_data_crops_data.csv
- Wang, Y., Han, J. H., & Beynon-Davies, P. (2019). Understanding blockchain technology for future supply chains: a systematic literature review and research agenda. *Supply Chain Management: An International Journal*, 24(1), 62-84.

- Westerkamp, M., Victor, F., & Küpper, A. (2018). Blockchain-Based Supply Chain Traceability: Token Recipes Model Manufacturing Processes. *2018 IEEE International Conference on Blockchain*. Piscataway, NJ: IEEE. doi:10.1109/Cybermatics_2018.2018.00267
- Willems, S. (2017). *Data Set—Real-World Multiechelon Supply Chains Used for Inventory Optimization*. Retrieved from INFORMS.org: https://www.researchgate.net/profile/Maxwell_Taylor/post/Hello_everyone_Im_looking_for_a_Dataset_of_any_kind_in_Supply_Chain_Management_SCM_Preferably_a_dataset_on_Supply_Chain_Risks_Thanks_Max/attachment/59d64b3479197b80779a550e/AS%3A479066462658560%4014
- Yaqoob, S., Khan, M. M., Talib, R., Butt, A. D., Saleem, S., Arif, F., & Nadeem, A. (2019). Use of blockchain in healthcare: A systematic literature review. *International Journal of Advanced Computer Science and Applications*, 10(5), 644-653.

APPENDIX

List of Publications

1. Chan, K. Y., Abdullah, J., & Khan, A. S. (2019). A Framework for Traceable and Transparent Supply Chain Management for Agri-food Sector in Malaysia using Blockchain Technology. *International Journal of Advanced Computer Science and Applications*, 10(11), 149-156. doi: 10.14569/IJACSA.2019.0101120