Master's Thesis

Blockchain-Supported Food Supply Chain Reference Architecture

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Abstract

A food security issue increased rapidly due to numerous food frauds and tragic incidents and overall growth in the scale of food supply chain network in the last years. Since the recent evolution of Blockchain technology, it promises high potential ability to guarantee and trace the originality of products in supply chain network

The main purpose of this research work is to build general Blockchain-supported food supply chain reference architecture model along with supplementary guidelines which could be applied in real-life supply chain cases with or without customization or inspire their design of supply chain system. A case driven bottom-up approach is used to create the reference architecture with the help of BOAT framework as a base tool to align the case details. A total of three food supply chain cases were utilized for the development of reference architecture and third case study of Mongolian meat trade supply chain was examined with the proposed solution and finally evaluated by the local experts.

I believe this reference framework will help fellow researchers and industry practitioners to use this as a base knowledge without beginning from the scratches because current literature lacks extremely in this field. In overall, I expect this work will contribute to the current literature in the followings:

1. To expand the implementation mechanism of Blockchain solutions in general supply chain cases especially in food supply chain.
2. To provide practical exemplary implementation of real life case scenarios
3. To provide detailed analysis of benefits and weaknesses of using Blockchain in food supply chain

Keywords: Blockchain, Food Supply Chain, BOAT Framework, Reference Architecture

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Explanation of terms and abbreviations

BOAT	Business, Organization, Architecture, Technology
BC	Blockchain
FSC	Food Supply Chain
RA	Reference Architecture
IoT	Internet of Things
MMSC	Mongolian Meat Supply Chain
FSCM	Food Supply Chain Management
IT	Information Technology
EU	European Union
SME	Small and Medium-sized Enterprises
RFID	Radio-Frequency Identification
QR	Quick Response
NFC	Near Field Communication
GMO	Genetically Modified Organism
BSC	Banana Supply Chain
B2B	Business to Business
SCMS	Supply Chain Management Systems
EBaaS	Ethereum Blockchain as a Service
BaaS	Blockchain as a Service
FSC	Fish Supply Chain
CRM	Customer Relationship Management
BPM	Business Process Model

Chapter 1

Introduction

1.1 Problem scenario

What is the current architecture of food supply chain and issues? And why do we need such BC-supported reference architecture?

Due to continuous increment of product consumption, especially huge leap in global trade and global shipping, supply chain field has been expanding and taking more attention to the researchers these days. While this increase in consumption boosts the scale of supply chain processes, consumers and other regulatory organizations also increased their interest to monitor the whole process of this product cycle especially for the sake of safety and genuine provenance of the product. Varies from the product characteristics, complete cycle of product movement from raw materials to finished goods to the customer differentiate in terms of scale and complexity of its management. Among these, food supply chain is one of the most sensitive and vulnerable context where consumer and regulators demand more control over the supply chain processes. A number of food safety incidents mounted in the recent years, from “2013 horse meat scandal” (beef product contained horse meat and pork) in Europe to “2015 Mozambique funeral beer poisoning” (beer served during funeral contained bongkrekic acid resulted 75 deaths and 230 people ill) and many more frequent incidents in China such as; infected snail meat (Amazonion snail meat served at restaurant caused 70 diners with angiostrongylus meningitis), stinky tofu manufactured in sewage (2007), melamine containing baby formula (6 babies died and 51,900 hospitalized) and many more. Such horrible incidents not only endanger the individual health and security of the society, but also decrease the trust in organizations which eventually deteriorates the development of economy. Therefore, society itself starts to demand more transparent, traceable and safe supply chain management. Thanks to the evolution of Blockchain, we could suggest one solid solution based on this technology. Due to its characteristics such as; immutability, transparency, security, and durability against outside attack (almost impossible to hack in practice), this technology promises to build absolute secure supply chain management.

Further chapters will introduce detail concept of Blockchain, case studies and proposed reference architecture models.

1.1.1 What is Blockchain?

The first Blockchain was conceptualized in 2008 by an anonymous person or group known as Satoshi Nakamoto and implemented in 2009 as a core component of Bitcoin where it serves as the

public ledger for all transactions. To simply define, a Blockchain, originally block chain, is a continuously growing list of records, called blocks, which are linked and secured using cryptography. According to Don & Alex Tapscott, authors Blockchain Revolution (2016) "the Blockchain is an incorruptible digital ledger of economic transactions that can be programmed to record not just financial transactions but virtually everything of value". In detail words, it is a long chain of a distributed database. Imagine a long spreadsheet, which duplicated millions of times according to how many people are accessing throughout the network of computers. Given the purpose of the transactions, this long spreadsheet updates every time something adds as an additional block. That is how Blockchain works. This spreadsheet database isn't stored in single headquarter or server room instead it is shared publicly by the nodes, members of the Blockchain network. Such characteristic makes Blockchain transparent. In addition, it can't be corrupted because it requires huge amount of computing power to override the entire chain network so that it is almost impossible for anyone to modify any information in the Blockchain. This cryptographic technology "offers a way for people who do not know or trust each other to create a record of who owns what that will compel the assent of everyone concerned. It is a way of making and preserving truths" (The Economist Staff 2015). Some scholars have argued that the invention of double-entry bookkeeping enabled the rise of capitalism and the nation-state. This new digital ledger of economic transactions can be programmed to record virtually everything of value and importance to humankind: birth and death certificates, marriage licenses, deeds and titles of ownership, educational degrees, financial accounts, medical procedures, insurance claims, votes, provenance of food, and anything else that can be expressed in code.

To explain its glimpse of technical side, a network of so-called computing "nodes" make up the Blockchain. Node, computer connected to the Blockchain network using a client that performs the task of validating and relaying transactions, gets a copy of the Blockchain, which gets downloaded automatically upon joining the Blockchain network. Together they create a powerful second-level network, a wholly different vision for how the internet can function. Every node is an "administrator" of the Blockchain, and joins the network voluntarily (in this sense, the network is decentralized). Such mechanisms create all those qualities briefly mentioned; immutability, transparency, security, and durability, etc.

1.1.2 Potential Blockchain application areas

Governance – By making the results fully transparent and publicly accessible, distributed database technology could bring full transparency to elections or any other kind of poll taking. Also, for example the app, Boardroom, enables organizational decision-making to happen on the Blockchain. In practice, this means company governance becomes fully transparent and verifiable when managing digital assets, equity or information.

Supply chain auditing – People are nowadays highly interested in the origins of products they purchase. To give assurance, distributed ledgers provide an easy way to trace and certify the backstories of the things we buy are genuine. For instance, it can be used to track the supply chain of ethical diamond. Another real-life example is UK-based Provenance company. It offers supply chain auditing for a range of consumer goods. Making use of the Ethereum Blockchain, a Provenance pilot project ensures that fish sold in Sushi restaurants in Japan has been sustainably harvested by its suppliers in Indonesia.

Protection of intellectual property – Digital information can be infinitely reproduced. However, this hurts content creators to lose control over their intellectual property and suffering financially as a consequence. Smart contracts can protect copyright and automate the sale of creative works online, eliminating the risk of file copying and redistribution. Real-life example is Mycelia. It enables musicians to sell songs directly to audiences, as well as license samples to producers and divvy up royalties to songwriters and musicians — all these functions being automated by smart contracts.

Identity management – Distributed ledgers increases the efficiency of methods to prove who we are with the accessibility of digitalized documents. Applying this in public services especially on document notary area, it could save cost and time dramatically.

There are lot more examples than mentioned above. In conclusion, any transactions based on record-keeping could be enhanced by the implementation of Blockchain. In this thesis, we explore the potential of its power in supply chain area.

1.2 Objectives

Numerous past studies in this field mainly focused on the potential opportunities to apply Blockchain in given context. From these studies, number of potential benefits and types of contexts by employing Blockchain would be observed. However, not many research has been made on engineering side of view, explaining how exactly Blockchain could be applied in given context, what kind of design elements should be considered, etc. Since current literature lacks on providing such engineering solutions to improve current business practices by using Blockchain, this thesis looked at particular scenarios to build general reference architecture which could help to solve the current problem. Reference architecture is a form of standardized template solution which built through experiences gained from past projects, so that it serves people as guiding tool to begin their new projects.

Therefore, a main purpose of this research work is to build general BC-supported food supply chain reference architecture model along with comprehensive guidelines which could be used as guidance for the implementation part. We believe such framework will help other researchers or any interested parties to save a significant amount of time by not beginning from the scratches because not much work hasn’t done in the literature yet. This presented reference architecture is designed on the general

requirements of the supply chain management system. To build more realistic reference model, number of case studies were utilized which are defined by BOAT framework and further illustrated by the proposed solution. Due to immaturity of Blockchain and limited implementation of the technology, this work intends to contribute to the current literature by achieving following sub-objectives:

4. To expand the implementation mechanism of BC solutions in general and especially in supply chain concept
5. To extend the context of BC-supported food supply chain architecture
6. To provide real-life case scenarios and solutions that have applied the proposed reference architecture
7. To provide detailed analysis on benefits of using BC in food supply chain context

With the successful implementation of BC in food supply chain, food industry could build long-lasting trust with the customers and regulators through safe, transparent, traceable and secure supply chain network.

Chapter 2

Background and related work

This chapter explains three key concepts that are essential and heavily utilized in this thesis. Those concepts are food supply chain and role of Blockchain technology in FSC and BOAT framework. For food supply chain part, overview of some major food markets worldwide considered to provide global take for this field. To emphasize significance of using Blockchain in FSC, second part offers key advantages of Blockchain technology in given context and detail summary analysis of potential sub-application areas. Lastly, definition of reference architecture and role of BOAT framework is explained in extensive manner because it is significantly employed for the analyses of the case studies beside its limited presence in the research literature. The detailed case analyses made by this BOAT framework will be used for the development of reference architecture in this study.

2.1 Food Supply Chain

Food is essential ingredient of sustainable human life, therefore research in food industry takes significant attention from academia. The entire food industry sector itself, mobilizes key industrial activities of many economies, such as agriculture, transport, manufacturing and service. In general, food supply chain is physical movement of food products from the time it was produced/harvested to processed, packaged, stored, delivered and retailed to the final consumer. Although majority of food supply chain follows fundamental steps of chain mentioned previously, due to variety of the products, such as; sea food, agricultural, forestry, etc. the structure of supply chain differs slightly. As it comes to food supply chain, efficiency and safety become the paramount issue topics because it involves business performance and sensitive health concerns which can't be avoided especially in modern well-awareness society. The report shows that about one-third of the produced food has been abandoned or wasted yearly (approximately 1.3 billion tons) (Manning et al., 2006). Of these, about 1 billion tons is occurred in food supply chain like harvesting, shipping and storage (Fritz and Schiefer, 2008). In case of fruit and vegetables industry, it was wasted by 492 million tons worldwide in 2011 due to the inefficient and ineffective food supply chain management (FSCM) (Gustavsson et al., 2011). Thus, more efficient food supply chain management (FSCM) is necessary to not only save food waste but to improve the quality of the FSCM to capture other issues like traceability and safety for better delivery of safe food products.

2.1.1 Literature on food supply chain framework

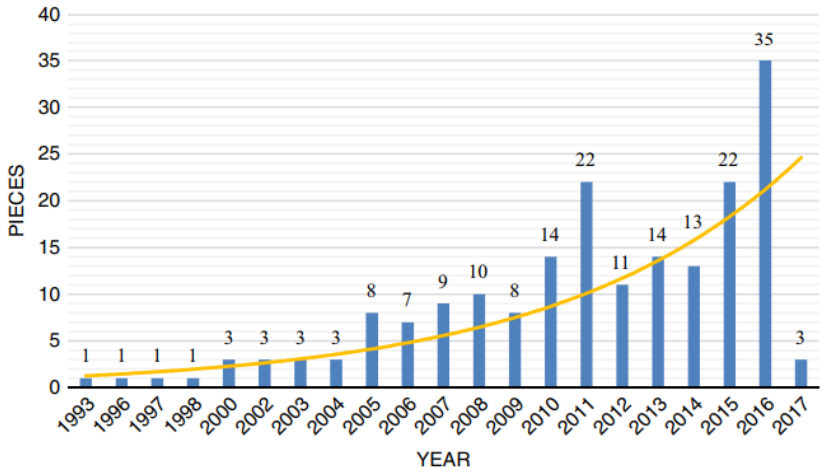
Food supply chain articles often divides in terms of IT-based FSCM systems, industry conceptual framework, or case-driven analyses, etc. 2017 review paper (Ray Zhong, Xun Xu, Lihui Wang, 2017),

based on about 200 research articles either published in leading journals or with high citations in the period of 1993 to 2017, analyzes the interesting pattern of previous studies to find frequency of specific FSCM systems observed and their implementation in certain industries. As a result, food quality, supply chain efficiency and food safety are more concerned among the chosen articles. Aligned with these results, direction of general FSC studies nowadays are reaching towards supply chain efficiency and supply chain traceability issues.

Figure 2. 1: Sample FSCM research articles chosen

Model	Food quality	Supply chain efficiency	Food waste	Food safety	Value chain analysis	Contributions
Caswell *et al.* (1998)	X	X				Proposes a Metasystems-enabled model Enhances product quality Considers the transaction costs and system efficiencies
Vorst (2000)		X				Introduces a KPIs-based model Assessment of the key impact factors in FSCM
Reiner and Trcka (2004)		X				Introduces an improved product-specific supply chain design model Enhances the performance
Gorris (2005)				X		Introduces a food safety objective model Concerns operational food safety management at different food chains
Beulens *et al.* (2005)	X	X		X		Introduces a network-based supply chain model Improves the products quality, safety and food chain transparency
Taylor (2005)			X		X	Applies lean value chain improvement Proposes a value stream analysis (VSA) model Uses a multi-echelon structures
Kim *et al.* (2006)			X			Presents a modified three-stage methane fermentation model Reduces the food waste
Manning *et al.* (2006)	X	X				Introduces an organizational business model Analyzes the efficiency in the integrated FSCM
Aramyan *et al.* (2007)		X				Illustrates a performance measurement Uses a balanced scorecard model Proposes applicable performance appraisal indicators
Trienekens and Zuurbier (2008)	X			X		Concern marginal costs and standards Revalue the cost/effectiveness of the food production
Oliva *et al.* (2008)	X					Introduces a system dynamic model Ensures the food quality
Akkerman *et al.* (2010)	X	X		X		Reviews the literature on related models in strategic network design, tactical network planning, and operational transportation planning
Ruiz-Garcia *et al.* (2010)	X		X			Establishes an architectural model Keep the quality and reduce waste
Parfitt *et al.* (2010)			X			Uses a data model Examines losses at immediate post-harvest stages
Marucheck *et al.* (2011)				X	X	Presents the operation management theory models and methodologies Examines food safety and values in FSCM
Garnett (2011)					X	Introduces a model to estimate food-related greenhouse gas emission Improves the total value of food supply chains

Figure 2. 2: Number of articles chosen each year



Figures shown represents the sample of studies the authors have chosen and indicates the number of relevant studies published each year in this field. As expected, number of articles mentioning food safety concern and solutions for provenance was very high most likely due to high number of food incidents. Majority of the articles tackled provenance confirmation issue through IoT development combined with other technologies that allows tracking and transparency in the FSC. Overall, it is notable that with the continuous development of Blockchain and IoT technology, number of articles published increases at faster rate.

2.1.2 Worldwide outlook on FSC

Europe: In terms of employment rate and value-added aspects, the food industry as a whole is the largest in the EU. Based on available data by 2015 (FoodDrinkEurope, 2015), employment amounted for 4.2 million and the turnover is €1,244 billion. However, despite the industry growth, European Commission recently pointed out that food industry is losing its competitiveness mostly due to lack of transparency in FSC (European Commission, 2016). In the past, to tackle this issue, 11 EU organizations such as AIM, FoodDrinkEurope, European Retail Round Table (ERRT), CEJA, EuroCommerce, Euro Coop, Copa Cogeca, etc. signed a Supply Chain Initiative document which is based on a set of principles of good practice to be followed. After two years, seven EU level associations agreed to implement the principles which have been converted into 23 languages.

Retailers in FSC are crucial since they sell thousands of different products with unique features and complexities and each run by its own supply chain. ERRT, an organization including the CEO's of Europe's leading international retail companies conducted a framework of the EU High Level Forum for a better food supply chain that often involves large number of business partners. Under the framework, leading retailers are going to build up a well-functioning and competitive supply chain in

maintaining good relationships with their suppliers so as to bring the best and most innovative foods and drinks to the customers (ERRT, 2013).

Logistics is a bridge between food retailers and manufacturers. It was reported that, in 2012, there were 24 million people employed in the food supply chain and 21 percent of the employment comes from logistics-related companies (European Commission, 2016). European Logistics Association (ELA) is a federation with over 30 organizations from Central and Western Europe. Recently, in order to achieve green logistics, ELA developed a sustainable supply chain scheme for FSCM (ELA, 2012)

North America: North America is the second largest food industry in the world with a turnover of about $5.75tn by 2017. In case of USA, by 2017, there were 38,571 grocery stores with $641,04 billion in revenues (Statista 2017). Especially through the last two decades, using advanced technologies such as bio-tech and ICT, food production and harvesting are innovatively improved (Fraser et al., 2016). Genetically modified organisms for instance with higher productivity and stronger anti-viruses are used in plants, mammals, fish, etc. (Hemphill and Banerjee, 2015). Increased utilization of automation and robots were significantly adopted in the warehouses of food and beverage supply chain. As an evidence of support for such improvement in processing manufactures and warehouses in terms of sorting, grading, processing and provenance, there has been numerous investments have been made in the recent years. In 2012, the US Government granted $50 million to research institutes and universities for robotics aligning with creation of the next generation of collaborative robots from the Obama administration's National Robotics Initiative (Pransky, 2015).

Asia Pacific: As the biggest economy in this region, China holds over 400 thousand food-related entities and has a turnover of €767 billion in 2011 (European Commission, 2016). Japan is the second in the area with €466 billion turnover between 2012 and 2013 along with about 1.4 million workers. India, Australia, South Korea, and New Zealand, as major food producers in this area, their turnovers (2012-2013) are 95, 62, 32, and 27 billion Euro, respectively. It is no debate that this area is the most important food and beverage supplier from its enormous turnovers. However, countries in this area, especially China, abuse too much manpower for FSC compared to Europe and North American countries. Lack of investment and effort for developing automated and efficient FSC plays a critical role in this statistic.

Chinese-made food products are prone to be low price, low quality, and low safety (Roth et al., 2008). A part of the reason is weak FSCM and lack of ability to control parties in the FSC by government or any other regulatory entities. Although China holds the largest number of food-related entities, majority of them are small and medium-sized enterprises (SMEs) that are too difficult to be classified and managed by integrated systems. Moreover, after numerous horrific food scandals that drew global attention, Chinese government established scrutiny systems, strengthened regulations, reformed laws

and increased investment on basic infrastructures in FSCM. After all these efforts, however, these efforts are still weak and not enough to reach safer food products at low price.

Japan and South Korea are relatively strict in terms of monitoring within the total FSCM because they believe that their foods represent their culture. Therefore, FSCM of both countries from initial point of production, warehouse and distribution are probably the best in the region of Asia Pacific. In case of Japan for example, fishing industry plays an extremely crucial role in Japanese culture. Due to limited space for refrigerators and food storage spaces, its fish supply chain uses time-constraint multiple-layered supply chain network to guarantee freshness and quality (Watanabe et al., 2003). Recently, these countries moved into a smart FSCM using advanced technologies such as Internet of Things (IoT). Different types of sensors are used to facilitate various operations within entire food supply chain (Park et al., 2016).

2.2 Blockchain in Food Supply Chain

Based on Blockchain's key attractive characteristics such as, immutability of records, decentralization, transparency, etc. Blockchain therefore confidently provide realistic enhancement solution for many domains of industries. Among those, supply chain industry is one of the well-cited domain, probably due to its nature of involving multiple parties together to execute logistic tasks. However, as usual behavior, lack of expertise in this field and the uncertainty of this risky technology prevents most industry leaders to commit for the adaption of Blockchain in their business. Despite the limited academically-provided knowledge of potential benefits of adopting Blockchain in supply chain industry, managers themselves indeed have even less information on this topic and in confusion to where to start in terms of technology deployment.

2.2.1 Blockchain key principles

As previously mentioned, key attractive characteristics of Blockchain allows new possibilities and direction of improvement in whole supply chain field especially in FSC. Main benefits of those characteristics or functions are generally explained in the following Table 2.1:

Table 2. 1: **Blockchain key principles in FSC**

BC characteristics	*Description*
Decentralized database	Each node in FSC network given access to entire database and complete history of all transactions. Database is not controlled or manipulated by any single party or central controlling party

Peer transactions	Transaction and any sort of communication occurs between nodes in FSC and each of them able to store information and pass it through other nodes. No central authority control transactions between nodes
Transparent network	Entire database including all transactions made between nodes will be visible to anyone in the FSC network. Nodes/users in this FSC network has a unique alphanumeric address that distinguished them from others. They can either remain anonymous or show their identity when they involve in transactions with other nodes in the system
Immutability of records	After transaction records entered in the database and users were updated, the records can't be tampered due to hash functions which links all the neighbor blocks. Other computational algorithms backup this hash function and make sure those input records are permanently stored, chronologically ordered and accessible to everyone in the network
Automatic Computational Logic	As an essence of Blockchain, transactions in such digital database/ledger are programmable. For the purpose of payment, or any other automatable transactions, users could create algorithms and rules that automatically triggers transactions between nodes. For example: smart contracts.

2.2.2 Blockchain application areas in FSC

Given this gray area between academia and practitioners, current limited literature and news articles provided by top technological journals still praise the uniqueness of the technology saying that Blockchain could become a universal supply chain management system. Following key points briefly represents how Blockchain could improve some basic tasks in supply chain concept:

Recording: the quantity and asset transactions - single items, packages, pallets, trailers, containers, etc. - as they move between nodes in FSC network

Tracking: purchase orders, cancel and change orders, product receipts, shipment notifications, or other trade-related documents

Verify: regulatory certifications or origin of products (provenance) to determine the if the product is under fair trade or meet certain standards, etc.

Linking: physical goods to IoT devices, bar codes, QR-codes, tags like RFID, NFC, etc.

Sharing: product information about processing procedures, or assembly, delivery, manual and maintenance with suppliers, etc.

Building on the basic task improvement above, more detailed application areas arise from the potential of the Blockchain in supply chain industry.

Table 2. 2: **Potential Blockchain application areas to apply in supply chain field**

BC characteristics	*Application areas*
Unique advantages	- Easier and accurate provenance information tracking - Reduced transaction costs - Decentralized network, removing centralized governmental institution - TranOpen access to information concerning the activities within the supply chain - Provides actors with the choice of buying sustainable products and transport - Customers gain the ability to evaluate the product or supplier before making a decision
Transparency and Compatibility	- Provides customers with the information they want concerning product origins and the freight - Reduces risk in regard to fraud or counterfeit goods - Easier to execute transactions by using hashes instead of physical documents - Use IoT for vehicle to vehicle communication - Enables monitoring, tracking and tracing transports - Better tracking, tracing and recycling of the product lifecycle
Complexity	- Ease paperwork processing - Effective usage of QR-codes, RFID, NFC-tags, WiFi, or iBeacons - A network working on a platform in purpose of exchanging intangible and tangible resources - Multiple active platforms to just access both private and public
Observability	- Effective tracking of fleet and vehicle performance history - Operate the internet of things - Simplifies exchange of goods and payment systems - Gradual increase of Blockchain start-ups, and active platforms

2.2.3 Traceability

Traceability is emphasized here over other abilities of Blockchain due to its high importance role in FSC network. Around early 2000s, the accurate and timely traceability of products and activities in the

supply chain has become a new factor in food and agribusiness. As recent IoT technology in this field develops, ability to monitor and trace the verifiability of the products in FSC increases and demand from customers also rose to meet the criterion of food product quality and safety. As mentioned in the beginning, frequent food incidents, increasing awareness to control products with GMOs and emerging conscious eating lifestyles (gluten-free, sugar-free, etc.) originally causes such trends.

Modern new agricultural industry is dominated by small number of big firms and trying to use integrated IT systems to build bridge between producer and customer. Due to enormous influence of such big firms, process of farming also intensified in ways that uses complicated chemicals, GMO modification and massive machineries. Such complicated structure of processes increases the uncertainty of the product originality in the market, thus leading consumers to increase their demand to access the information of products.

Although traceability is a preventative method in food safety and control, it also could be used to quickly facilitate the recall and investigation procedure when food incident hazard occurs. This standing capability for allowing consumer to have full access to trace the products at any stage in the food supply chain is crucial to increase the confidence of consumers and ease the public food safety concerns. The advancements in both IoT and information technology to capture data log, storage and evaluate, GPS data retrieval and other manufacturing technologies provides opportunities for industry practitioners and academia to contribute their creative work for the implementation of traceability applications.

Process of traceability to life history of product begins from labeling. The logic of mechanic procedure is simply to attach mark on the desired item (raw material, livestock, fish, etc.) and store the data on this mark to the scannable bar code of the product. In terms of livestock, traditionally ear-tag has been often used to contain essential information such as age, vaccinations, color, breed, etc. After this synchronization, the item becomes ready to launch in the supply chain network and simply dictates by the bar-coded label and managed by FSCM systems.

2.3 BOAT Framework

2.3.1 BOAT framework and its four dimensions

The BOAT framework is comprehensive tool to define any form of networked business into organized and detailed separate structures to build complete definition of the business. BOAT acronym stands for (B)business, (O)organization, (A)architecture, and (T)technology. Nowadays, networked business is usually a mix of business-oriented elements and technology-oriented elements to guarantee customer satisfaction and efficient operation within network. When we want to perform a good analysis of an existing networked business scenario or a well-structured design of a new scenario, we need to make a clear separation between different elements of a scenario to arrive at clear and well-founded choices:

the *what* and the *how* of a scenario are not the same thing and can be seen from different perspectives. For this reason, four dimensions of BOAT framework are employed to separate these element in a networked business scenario. The goal of BOAT framework is to clearly separate boundaries of networked businesses to give complete definition of business. Below is the detail explanation of its four dimensions.

Business (B): the business aspect generally describes the business goals of networked business. In other words, it explains why this business scenario exists or should exist. Answers for this part varies from new market entry, reorientation of interaction with customers, business structures and directions, etc.

Organization (O): the organization aspect describes how business are organized in a way to achieve what has proposed in business aspect. Organization structures in the organization and the business network level, business processes inside organizations and throughout organizations in a business network, business functions and business services are the main components here, complemented by considerations of how to manage and change business operation.

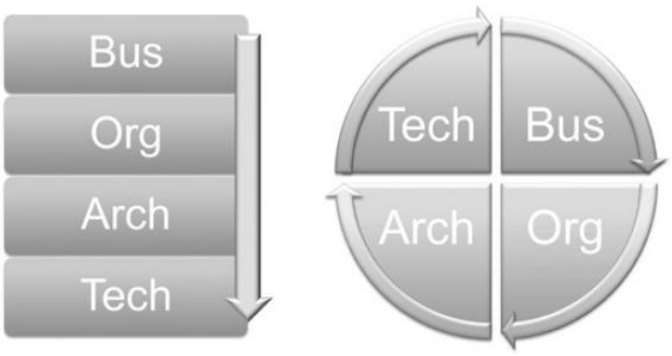
Architecture (A): the architecture aspect involves the conceptual structure or blueprint (i.e., the architecture) of automated information systems required to make the organizations defined in the organization aspect work. Shortly, architecture aspect describes *how* automated systems support the involved organizations in a conceptual, high-level fashion.

Technology (T): the technology aspect describes the technological realization that inspired in the architecture aspect. In most cases of networked business scenarios, the technological part is the vital because technological solution is where the business system is built. Technology aspect covers features from information and communication technology, including software, languages, communication protocols and hardware etc.

2.3.2 Types of BOAT frameworks (stack or wheel)

In traditional information system design practice, development of systems takes place in a linear way beginning from the business to the technology aspect. As shown in Figure 2.3, figure in the left shows boat stack model which reflects traditional approach as mentioned previously.

Figure 2. 3: **BOAT stack and wheel model**



But in the networked business field, the relationship between business and technology is not likely linear. As traditionally business initiates technology development by stating new requirements, but technology also pushes business by creating new opportunities. Not like stack model, initiation of business could begin either from opportunities created by technological advancement or opportunities created by business ideas. However, initiation could also begin from organizational or architecture aspects as well in case networked business scenario is mainly depends on regulation imposed by government or specific standards. Therefore, in wheel model, any of the aspects could be stepping stone for the development of networked business scenario.

This thesis used BOAT framework extensively to show complete definition of chosen three case studies. Each dimension has its own detailed protocol to be applied in chosen context. Chapter 3 discusses two cases studies in full detail with most essential parts of BOAT framework.

Chapter 3

Reference architecture modelling

This chapter provides complete definition of two case studies with BOAT framework and proposed reference architecture solutions along with comprehensive guidelines for the implementation. First part of the chapter briefly explains what reference architecture is and why case studies were used as methodology to build RA. Further parts will introduce case study analyses and chapter ends with proposed RA solutions and other guidelines.

3.1 What is reference architecture?

Every system has an architecture regardless of the context. Just like blueprint of construction, system architecture is "the structures of the system, that comprise software elements, the externally visible properties of those elements and the relationship among them". Reference architecture is certain types of architecture that provide general guidelines for the base of system design during its initial phase.

- In this thesis, reference architecture is defined as combination of module solutions and number of basic requirements necessary to build new blockchain system for real-life food supply chain cases. By comparing important elements in given two cases and other literature sources (new blockchain startup companies) we list which elements represent the general view and combined those into reference architecture template solution.

Depending on the context, reference architecture is classified as either practice-driven or research-driven. Practice-driven reference architecture is defined when there is sufficient amount of past practices accumulated in certain domain. On the other hand, research-driven architecture attempts to define futuristic design viewpoint based on all sort of research studies; case studies, conceptual research studies, etc. Reference architecture is in another word, the preparation phase for building concrete architecture.

- This thesis pursued research-driven approach to build specifications for the design elements of the reference architecture. Chapter 4 provides expert evaluation result for the real-life case study as part of assurance for the reference architecture in this study.

In modern days, development of system software is incredibly fast in all domains of systems and each software are usually developed by separate developers to be integrated later. As a benefit, reference architecture could be used as sort of evaluation method for the final systems, however, its value is much greater prior the system is developed. Building integrated huge system is extremely costly and time-consuming assignment. Cutting cost and time is therefore crucial and employing well-planned reference

architecture is one of the best solutions before developing the systems. Robust reference architectures provide useful guidelines for the practitioners the ways to efficiently plan the system through excluding unnecessary functions, shorter pathway between nodes and other time-cost saving techniques.

3.1.1 Targeted audience

Due to its rather practical implications than academic, findings of this thesis are primarily directed for those industrial practitioners who are in charge of designing or evaluating the overall scheme/quality of the blockchain system. Those targeted users are usually system designers, software product managers, quality assurance engineers and system consultants. Main duties of these practitioners are design overall architecture of the system, manage and communicate with relevant external and internal parties, build system evaluation test, and track quality assurance metrics respectively. The findings of this thesis provide suitable knowledge on these topics.

Secondary audience of this thesis will be academic researchers in the field of Blockchain development for supply chain. We believe the dimensions of the reference architecture will be useful knowledge to develop further research topics in this field. To build the dimensions, we have researched 24 currently top tier Blockchain supply chain companies and compared their service specifications to the thesis' reference architecture.

3.2 Case studies

List of case studies tested for the proposed smart food ledger reference architecture

1. Banana supply chain (Farmers in Southeast Asian to domestic and international markets)
2. Fish supply chain (Fishers in South America to domestic and international markets)
3. *Mongolian meat supply chain (Herders in Mongolia to domestic and international markets)

Case study of Mongolian meat trade supply chain is discussed for detail in Chapter 4 for reference architecture evaluation purpose.

This thesis used case-driven, bottom-up approach to build RA for the smart food ledger which is the BC-supported FSC. According to Robson (1993, p. 5), case study research is "… a strategy for doing research which involves an empirical investigation of a particular contemporary phenomenon within its context using multiple sources of evidence". Two case studies, banana and fish supply chains, start with overview and further explains characteristics and challenges. After initial introduction, four dimensions of BOAT framework analysis follows and finally applied to RA solutions.

Benefits of using case study - a case study approach enables development of detailed knowledge about a certain phenomenon. One of the objectives of this thesis is to investigate how food supply chain

system operates and how it affects the parties within the network. By employing case studies, we accumulate sufficient amount of initial knowledge on the FSC context to build certain pieces of architecture to eventually build more complex architecture. Case studies also allows to capture realistic viewpoint of the certain context, so that it helps to create realistic model. Finally, case studies in general create new insights and help authors to see the problem in multiple angles.

3.2.1 Banana supply chain

Case overview

This fictive case study of banana supply chain (BSC) demonstrates the chain of distribution points for banana to deliver from the field in the village of Southeast Asia to the home of consumer at both domestic and international markets. Special farming villages designated for growing only bananas in Southeast Asian territory starts this chain. All the procedures from seeding to harvesting are done by farmers in the field. After harvesting, processing manufacture located in the farm land take care of the cleaning, tagging, packaging. The processing manufacture is relatively big and capable of handling plenty of trucks worth of bananas daily. Next, either collectors or village wholesales themselves will send their trucks to pick up the products to deliver to the warehouses owned by village wholesalers. Due to inconsistent amount of harvesting, collectors mediate as middleman between farmers and village wholesalers in this short chain. Once bananas are successfully collected at the central hub of village wholesale, they either send about half of the amount to the domestic markets through agents at central domestic market or directly deliver to shipping ports nearby for the export to international markets. Arrival of domestic bananas mostly supplied to supermarkets, restaurants, and some small vendors to eventually reach to the end customers. On the other hand, bananas in the shipping containers go through detailed custom check at each arriving country and supplied to wholesales, supermarkets and restaurants to end up in the hands of international consumers.

Challenges

This BSC has been existed in the market for over a decade. Each station; farm, village wholesales, shipping port, etc. have its own offices which records the sale, traces the shipment and uses their own separate management software to run their daily operation. Due to increasing amount of demand from the customers for the originality of the bananas and other provenance information such as; seed date, harvested date, pesticide type, location of farm, etc. this BSC is facing an issue to provide such information at faster and accurate ways. Poor limited communication between parties in the chain, separate management systems (not integrated), inconsistent slow network speed are the beginning issues to prevent this supply chain work in synchronized operations to provide integrated information to the customers and to each other.

Another big issue in this BSC is unfair commission rates charged among the players. Village wholesalers charge the most amount, which is 15% of the commission from the farmers and further players charge indefinitely between 5-10% commission at each transaction. As a result, farmers receive the least amount of profit in overall BSC.

BOAT framework is being used to understand detail structure of the supply chain and illustrate it in standardized format for the preparation of further analysis. Detailed description of four dimensions (Business, Organization, Architecture, Technology) are written as follows

Business dimension: BSC itself is a B2B business because they are essentially focused on exchanging products for the value between each other. What they sell in BSC is bulk amount of banana, tangible good, that creates values for each party. In terms of time scope, it is both static and semi-dynamic. Banana trade is one of the stable businesses, therefore partners in this BSC enjoy flourishing benefits in long-term partnership and rarely replaced by new players. However, some international buyers and brokers are changed occasionally due to economic crisis, business revolution, and other country-specific factors.

In terms of drivers, they are mainly focused on expanding their market to different countries to keep their survival in long run. As international shipment and trade opportunities become easier, farmers' passion to partner with new businesses rise with it. On the other hand, they also start to understand the importance of technological importance in traceability and financial transactions. Such new technologies help the BSC management easier and make the BSC to provide detailed information to the customers. Therefore, their goal is to increase the efficiency of BSC operation in every possible way.

BSC is originally created to replace the slow banana trade to utilize the possibility of delivering bananas to the other markets and increase the trade scale enormously. In terms of structures, BSC is network of multiple parties with mutual interest of delivering products to the customer in timely and efficient manners.

Overall business dimension classification is represented in the following Table 3.1:

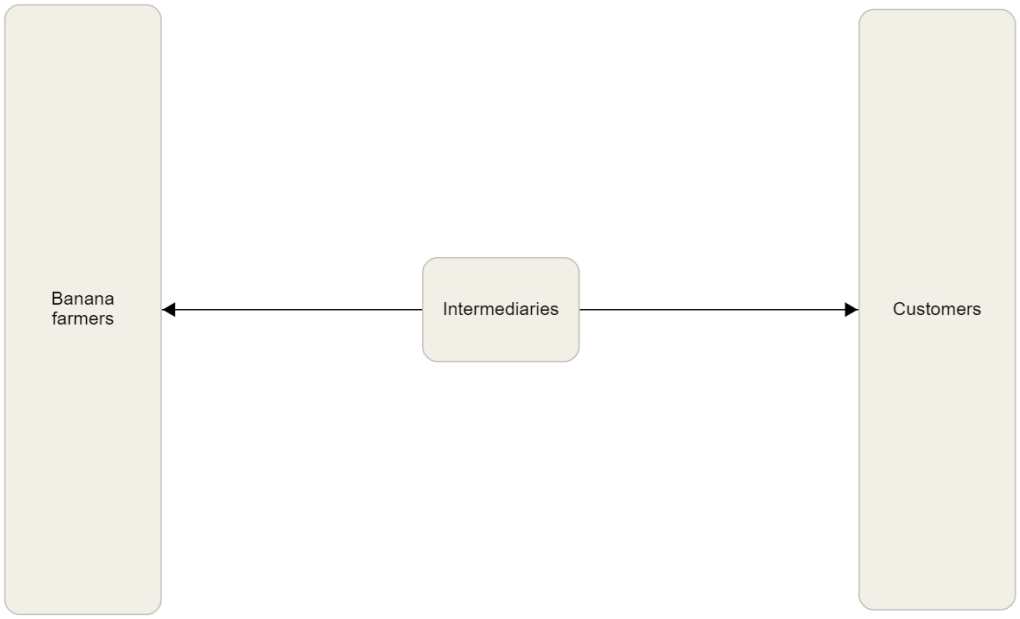
Table 3. 1: **Business dimension of BSC**

Case study: Banana Supply Chain (Southeast Asia)		
Parties	B2B	Parties in BSC exchange goods and values with each other
Objects	Physical goods (bulk goods)	Tangible goods, bananas in the case, are physically exchanged between parties

Time Scope	A static, semi-dynamic	Parties in the BSC are long term partners and they are replaced rarely
Drivers	Increasing reach/richness/efficiency	Mainly geographic reach (export to more international markets) This BSC wishes to increase the tactical level of efficiency (increase quality of operation and communication among parties)
Directions	On-time and on-line business/Completely automated business/Enhanced CRM	Focuses on increasing the accessibility and usability of supply chain management software (SCMS) Optimization of SCMS for instant control of traceability and retrieve product information for the consumers
Networks	Substitution	BSC replace traditional BSC to increase cost and time efficiency of entire BSC
Structures	Dynamic partnering, demand chain	BSC consists of multiple long-term partners that work as a unit to reach single purpose, deliver goods to end customers Amount of supply unit heavily depend on producers' capability in many cases
Model	Producer	
Revenue stream	Margin on sales price of objects, commission fee	

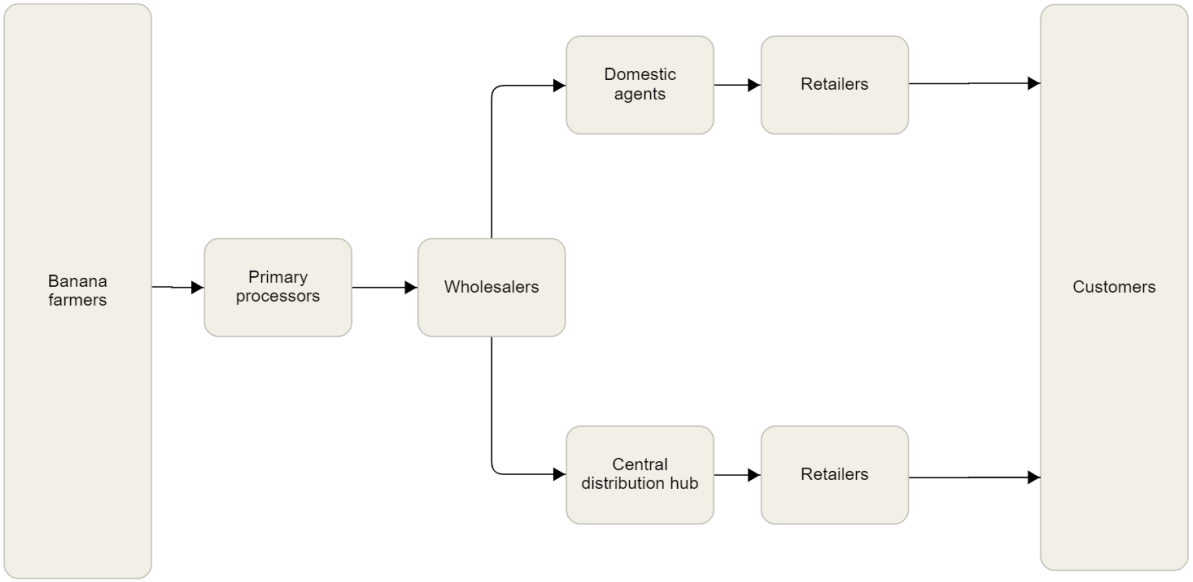
Organization dimension: this dimension explains and analyzes how BSC operates and shows detailed structure of each nodes in illustrated views. First Figure 3.1 (Level 1) demonstrates the simplest structure of BSC. Main purpose of the FSC is simply transfer banana to the end customer.

Figure 3. 1: **BSC organization structure (Level 1)**



However, due to physical distances, product processing requirements and other regulatory issues, multiple intermediaries add up in between the parties in the FSC. Such detailed viewpoint is illustrated in the next Figure 3.2 (Level 2).

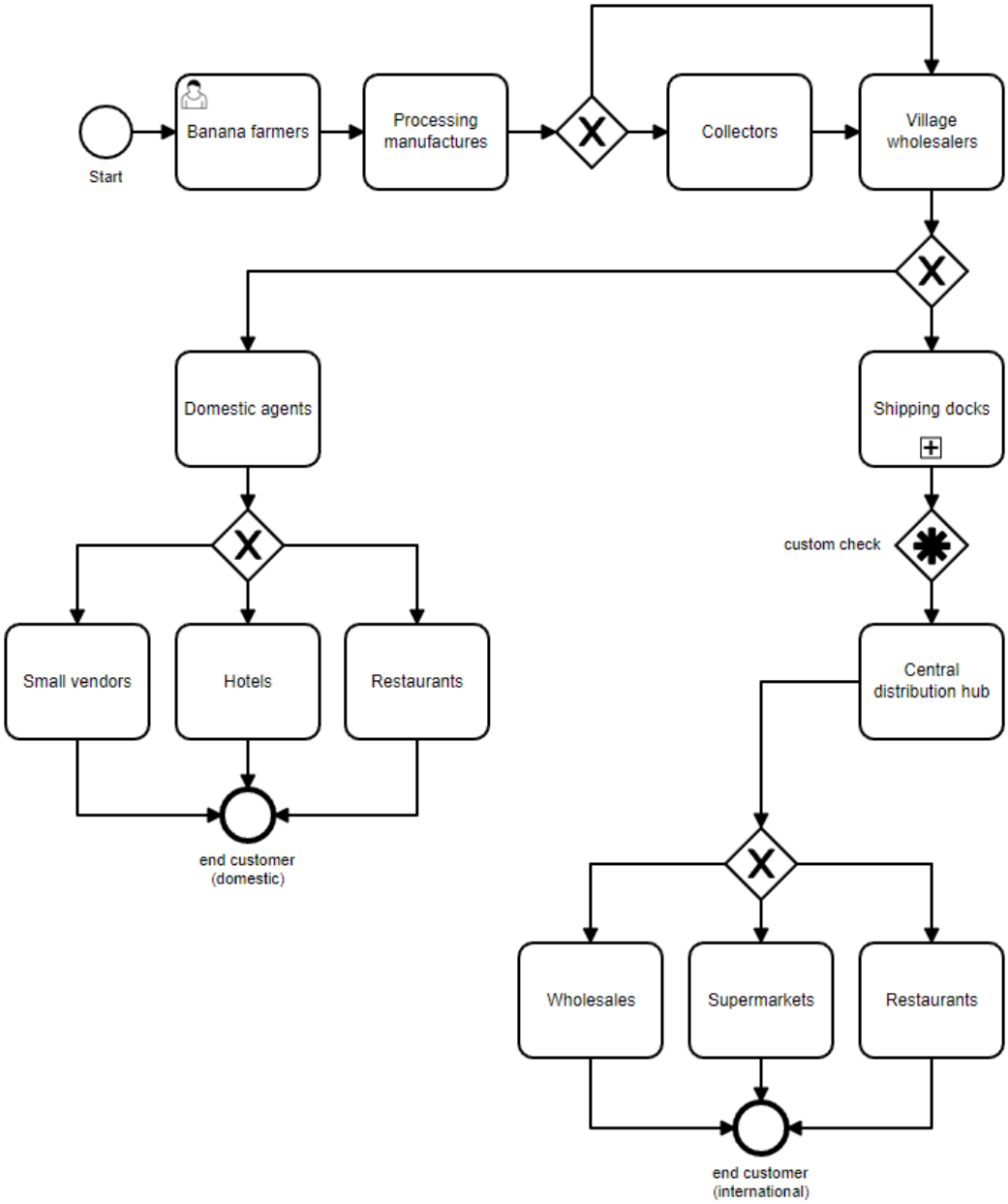
Figure 3. 2: **BSC organization structure (Level 2)**



BPM: Next Figure 3.3 captures the BPM of this BSC in detailed view including all relevant intermediaries in single model. Collectors, village wholesalers, domestic agents, central distribution hub are the main intermediaries in this BSC. As shown in the model, all the harvest pass through processing stage and either sold to collectors and eventually sold to village wholesalers or directly sold

to village wholesalers. Then, village wholesalers decide what amounts to sell to domestic agents and export markets. Compared to other highly perishable foods, bananas require relatively less effort in terms of processing and packaging. Therefore, bananas destined for export markets rarely go through another processing to be loaded in shipments. Once the products pass through custom check and arrived at central distribution hub, they are further shipped directly to contracted nodes (wholesales, supermarkets and restaurants) in timely manner to prevent products get expired.

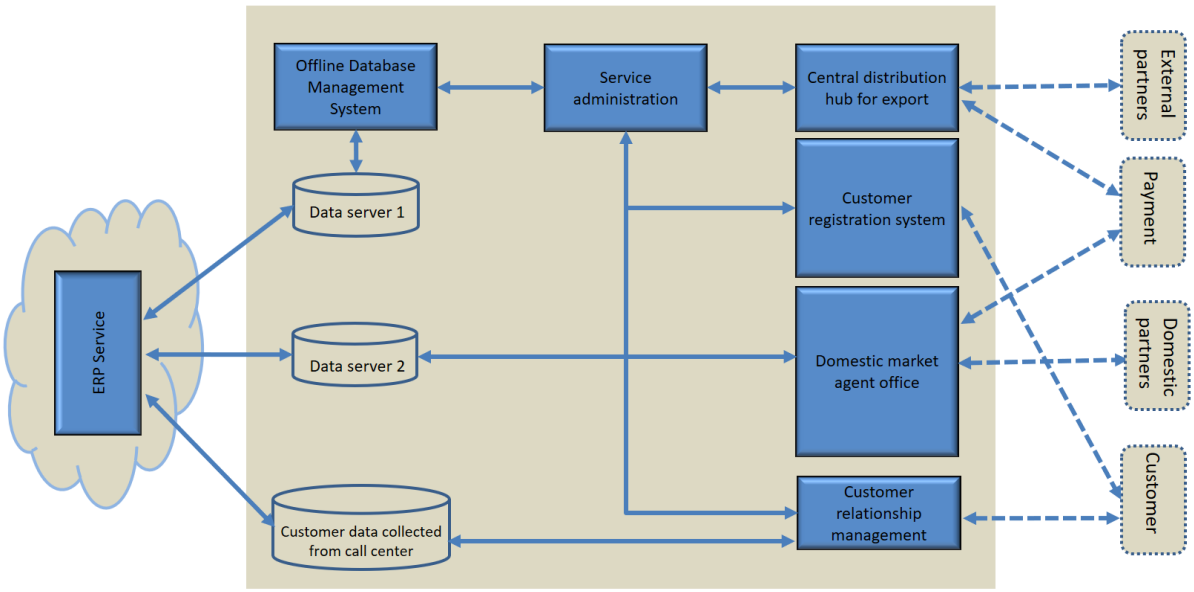
Figure 3. 3: **Business process model of BSC**



Architecture dimension: This dimension focuses on how to architecture the complexity of internal and external running systems that manage the networked business. In our cases, we focused on party-

level architecture because supply chain cases consist of parties within the network and relationship between them is the most important. Following Figure 3.4 shows party level architecture of BSC in detailed view emphasizing main functions of the network and how they pass through big parties in the chain. Offices held in central distribution hub are mainly responsible for contacting external partners and recording their input in the main database system, which then store the data in the company server. Due to limited size of domestic partners and small amount of trades, domestic market offices store significantly low data in their local server, which is usually cloud server. Regardless of the size, all databases are managed by some sort of ERP systems.

Figure 3. 4: **Party level architecture of BSC**



Technology dimension: this dimension basically tries to capture what types of software, devices and technologies the company use for their business models. In case of supply chain cases, ERP type of systems which facilitates parties' shared knowledge is crucial. Party level architecture helps to find those attributes easily.

In the case of BSC, currently village wholesalers use simple SCMS tools which allows them to record mainly purchase-order processing, logistic management and keep goods receipt. Domestic agents also share same SCMS tools as wholesalers while they use functions for sales and distribution. On the other hand, more sophisticated tools are being used by central distribution hub because they are responsible for keep track of international shipping orders, adjusting customer-requirement processing and other customer relationship duties. Combination of full package of SCMS and ERP tools are being used in this part of the chain.

Blockchain role in this part: Although parties in BSC use sufficient tools to smoothly operate the business in this case, it is being challenged by future demand of customers. Due to mostly health concern issues and number of food incidents, customers' demand for traceability and transparency attributes increased dramatically in recent years. Customers simply want to be able to know lifecycle of product from when and where it is made until it reaches to their hand. Although this demand sounds clear enough, parties in BSC can't fulfill this demand with the current tools and practices they have. Each party use different tools to record the product information and there is no integrated database where anyone can access for the full information. In the early stages of the supply chain, some products are being recorded in paperwork so that some information also get lost in the way.

Private blockchain solutions are recommended for this case due to its size and importance of internal auditing. As shown in the following Table 3.2, public blockchain is not appropriate because it requires sophisticated tools and slows the transaction speed while speed is crucial in supply chain case. Also, importance of keeping business secret is critical especially for small-sized intermediaries.

For the development of system, we recommend parties in BSC to use currently available BaaS (Blockchain as a Service) tools to cut cost and save time. Currently Microsoft has partnered with ConsenSys to offer Ethereum Blockchain as a Service (EBaaS) on Microsoft Azure. Also, IBM(BueMix) has partnered with Hyperledger to offer BaaS to its customers such as Food Trust modular solutions. Those tools are specifically designed for industry-specific purposes; therefore compatibility will not be an issue.

Table 3. 2: **Comparison of public and private/federated blockchain**

	Pubiic	Private/Federated
Access	• Open read/write	• Permissioned read and/or write
Speed	• Slower	• Faster
Security	• Proof of Work • Proof of Stake • Other consensus Mechanisms	• Pre-approved participants
Identity	• Anonymous • Pseudonymous	• Know identities
Asset	• Native Asset	• Any Asset

3.2.2 Fish supply chain

Case overview

Second case study of fish supply chain (FSC) demonstrates the comprehensive chain of distribution channel for fish and other seafood products to deliver from the fishing farm in South America to the hands of consumer at both domestic and international markets. Fishing farmers harvest the catch from nearby designated sea area only for hunting. Divers are mainly responsible for harvesting benthic resources, such as black rock snails, octopus, crab, razor clam, and pelagic fish. Large fishing boats are on duty to bulk hunting for other marketable fishes for both high and low-end consumers. Once the harvesting completed, overall catch will be transferred by so-called collectors, delivery company, to the primary processing stations which is located approximately 40km from the fishing farm. Delivery company charges commission fee for the work of delivery but never obtain ownership or purchase catch.

Main purposes of primary fish processing manufactures are sorting, grading, bleeding, gutting, washing, chilling, storing, and loading to the trucks. These processing manufactures are capable of handling more than 20 tons of fish daily. It is notable that some specific fish sorts are stayed alive to be delivered alive for the high-end customers. After fishes went through primary processing, collectors will transfer them either to minorista (minor commercial vendors) for domestic customers or large local seafood buyers. Minorista usually purchase high-end fishes to further sell them back to hotels and restaurants for their upscale seafood menu. About half of total quantity purchased by minorista goes to small vendors to supply their low-end customers' demand.

On the other hand, catches purchased by large local seafood buyers face much longer journey to reach their end customers. About two third of the total catch bought by these buyers are designed for international high-end markets; US, The EU, Hong Kong, and China. Therefore, the whole batch including low-end products designed for domestic markets, pass through secondary processing manufactures which construct careful treatment of processing such as, cutting, salting, ionizing, adding acids, and vacuum packing, etc. Then, large local sellers purchase those catches from all secondary processing manufactures and deliver them to the domestic central fishing market. Some batches, mostly low-end fishes, are directly sold to domestic customers through retailers owned by the large local sellers while most of the quantities directly sold to so-called mayorista, who control the export markets. Due to strict inspection demanded by high-end international buyers and brokers, mayorista send the whole exporting batch of fish to the last exclusive processing stations for careful grading, smoking, salting, freeze-drying, freezing, temperature control adjustment, and special packaging, etc. Once the products become ready to be delivered, most of the batch transfer through sea shipment and rest delivers through freight to reach some high-end restaurants and hotels.

Challenges

A main FSC, including fish farmers and local big buyers has operated this trade supply chain for over twenty years. Due to slow technological adjustment and geographically isolated farming areas from the downtown, parties in the whole FSC are not well connected in terms of system integration for managing products, ownership and provenance issues through the FSC. Most of the trade-related documents still pass through in paper documents, it is hard for all ends of the parties to trace back and forth to monitor their status. Efficient SCMS is necessary in this FSC for the smooth transactions.

For the recent years in the Western markets, high-end fish customers increased their needs for safe and high-quality products due to number of horrible food incidents scared people through SNS and other news channels. As a result, some of the big fish supplying companies started providing such services for limited seafood products and other players in this market face to improve their technology to provide same service to the customers to secure their market share.

Fair trade issue is another overwhelming topic in this market. As a common issue in most products, that pass through multiple parties to reach end customers, FSC is criticized for providing less profits to the real fish farmers than the other middleman in the network. Many activists and sensitive customers challenge retailers and other-related parties for fixing such issues and such resistance slow down the market in some ways. However, the issue itself is more challenging to be fixed because there is no such solid integrated transparent scheme which shows how much money each parties charge.

FSC characteristics

FSC is basically consist of three types of players as follows:

- **Farmers/supply** – focuses on harvesting/creating the raw materials and directing the delivery to the processing manufacturers including how, when and where the location is.
- **Process manufacturing -** focuses on transforming these raw materials into marketable semi-finished or finished products.
- **Distribution** - focuses on delivering these products to the designated parties through safe warehouses and tracks**.**

Preference of Western markets

Consumers in the Western markets (US, The EU) usually prefer seafood in cooked forms and pay extra attention on the food processing techniques. Convenience therefore plays a huge role in those markets. Single parent, busy mothers and house wives resist to buy unprepared fish products due to time-consuming preparatory work. Due to many seafood companies already adapted to provide ready to cook products, customers in these regions are used to pay premium price for such products. Weekend

shopping trait is common in Western markets, and the fish markets put high effort to ensure convenient trade on those days.

Modern consumers in general, especially in these regions, are more concerned about food safety than ever and promotion of wellbeing and healthy diet are increasingly emphasized. For the safety concerns, European Union (EU) market follows the protocols of EU directives food safety and sanitation, and US market is based on Food and Drug Administration (FDA) requirements. Such wealthy markets are willing to pay extra for the maintenance of safer food in this FSC.

Certification and labelling

Proper labelling and certification are crucial in this FSC and they help to identify product whether they follow certain standards and regulation such as, fair trade, origin of produce, sustainability, organic production, etc. Over the past decade, variety of seafood certification standards were well developed and been followed in both developed and developing countries.

Labelling is simpler way of providing accurate information to the customers than assuring multiple certifications. For example, The EU adopted certain regulations that require labelling of all fisheries and aquaculture products. According to these regulations, all seafood products sold in these markets must provide at least following information on their labels; the origin country of catch, processing techniques, commercial name of the species, etc.

Additional sustainability requirement labels:

- "Dolphin-safe" and "Turtle-friendly" labels on tuna and shrimp
- Nordic Technical Working Group on Fisheries Eco-Labelling Criteria
- Marine Aquarium Council certification
- Global Aquaculture Alliance codes of practice and certification
- ISO 14000 series on environmental management performance
- MSC label on sustainable fisheries

Technology

The application of modern fisheries technology starts from culture and ends to export of the product. Post-harvest fisheries technology involves processing, preservation, handling, harvesting, marketing etc. Developing countries, where tropical weather and under developed infrastructure contribute to the problem, losses are sometimes staggering proportions. Losses occur in all operations from harvesting

through handling, storage, processing and marketing. Many developing country producers were marginalized from global supply chains due to their poor maintenance of quality standards. In general, low-tech developing country suppliers earn less for their resources; whereas industrial nations earn extra premiums, by marketing information systems, supply chain management, quality assurance regimes, transport, handling, post-harvest and production technologies.

Cold chain

Reliable temperature maintenance is the key important feature in fish and fishery product transport. People who are involved in the handling and transporting of perishable commodities are responsible for their part in the cool chain. Breaks in the cool chain can result in irreversible damage to the quality of foods. In the transport of perishable products into remote regions ideal procedures may not always be possible and so in these instances early planning will allow products to be delivered as efficiently as possible. Distributors and transporters need to be able to manage frozen, chilled and odour-producing foods, as well as ethylene-producing and ethylene-sensitive products. Many developing countries are lacking such facilities and post-harvest losses are very high. A large portion of the harvest is discarded without marketing. In one hand, this is threat to the resources base and on the other hand it leads to poverty. This means important decisions related to storage facilities, truck design and capacity as well as supply patterns that will be required to meet food safety regulations. Maintaining the cool chain is essential to minimize product deterioration and maximum shelf life of the product. Many potential problems in the supply chain can be avoided or effectively managed by understanding the critical handling issues and carefully planning each load.

BOAT framework is being used to understand detail structure of the supply chain and illustrate it in standardized format for the preparation of further analysis. Detailed description of four dimensions (Business, Organization, Architecture, Technology) are written as follows

Business dimension: Fish farmers aren't able to deliver fish directly to the customer therefore it is suitable to see this FSC as whole B2B business structure since most parties in the FSC are exchanging good and values between each other. The object of FSC is straightforward, to deliver fish (tangible good) in preferred processed variety to the hands of customers.

In terms of time scope, it is both static and semi-dynamic because many of the partnering restaurants and hotels change periodically although base brokering partners essentially stay in the FSC for long period of time. Economic downfall, natural disaster, quality control issues, and many other issues affect the constant change of partners in product receiving end. The essential driver of existing FSC is to expand their market while providing as efficient service as possible. If there are new markets willing to

make trades with fish farmers, supply part is always manageable. Therefore, their drivers are increasing both reach and efficiency according to BOAT business dimension.

In terms of directions, all parties in FSC have single interest to gain trust from customers through safe and high-quality products delivered by smooth transactions. In the most Western markets, demand for safe and high-quality fishes are increasing and they are willing to pay extra for the assurance cost. To meet their demand as well as not losing the market share to other competitors, this FSC is willing to devotes their resource for better SCMS and CRM.

Overall business dimension classification is represented in the following Table 3.3:

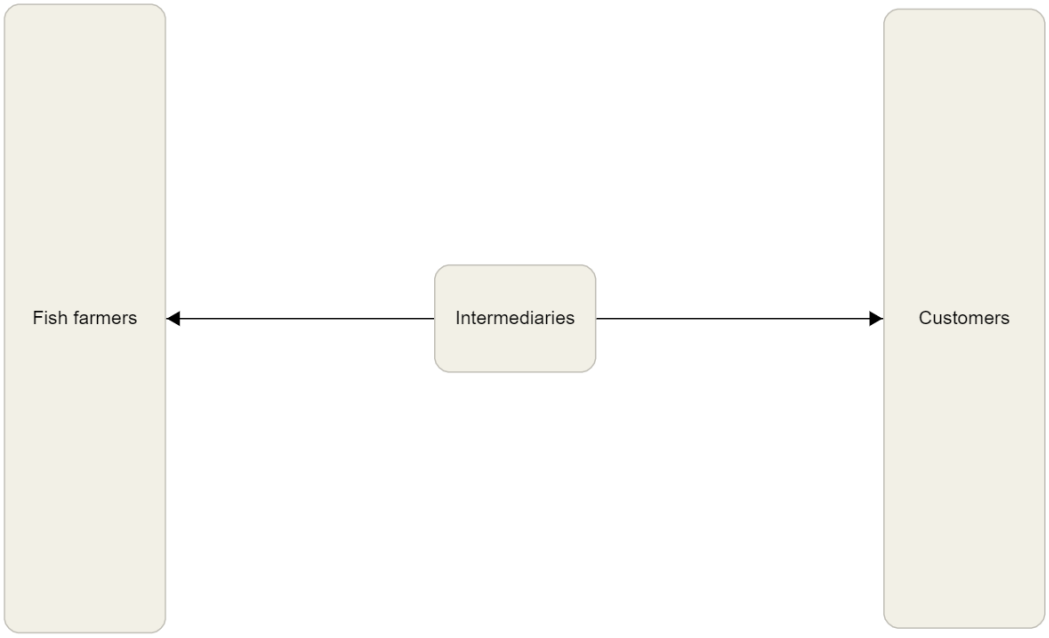
Table 3. 3: Business dimension of FSC

Case study: Fish Supply Chain (South America)		
Parties	B2B	Parties in FSC exchange goods and values with each other
Objects	Physical goods (bulk goods)	Tangible goods, seafood products in the case, are physically exchanged between parties
Time Scope	A static, semi-dynamic	Some parties in the BSC are long term partners however, many of the brokers and end-customers, such as hotel, restaurants replaced over time due to mostly quality requirement and price issues
Drivers	Increasing reach/efficiency	Geographic reach (export to few more international markets because they have significant supply when there is demand) The FSC wishes to increase efficiency of operation at FSC stations The FSC wishes to increase the tactical level of efficiency (increase quality of operation and communication among parties)
Directions	Completely automated business/Enhanced CRM	Focusing on needing simple integrated supply chain management software (SCMS) Optimization of SCMS for instant control of traceability and retrieve product information for the consumers and regulators

Networks	Reintermediation and substitution	FSC creates new functioning nodes in this supply chain to increase the quality of FSC FSC replace traditional FSC to increase cost and time efficiency of entire FSC
Structures	Dynamic partnering, dynamic outsourcing, demand chain	FSC consists of multiple long-term partners that work as a unit to reach single purpose, deliver goods to end customers Fish farmers and some middleman sometimes outsource non-partnering processing manufactures for emergency situations Amount of supply unit heavily depend on producers' capability in many cases, such as natural disaster, quality issues, etc.
Model	E-producer	
Revenue stream	Margin on sales price of objects, commission fee	

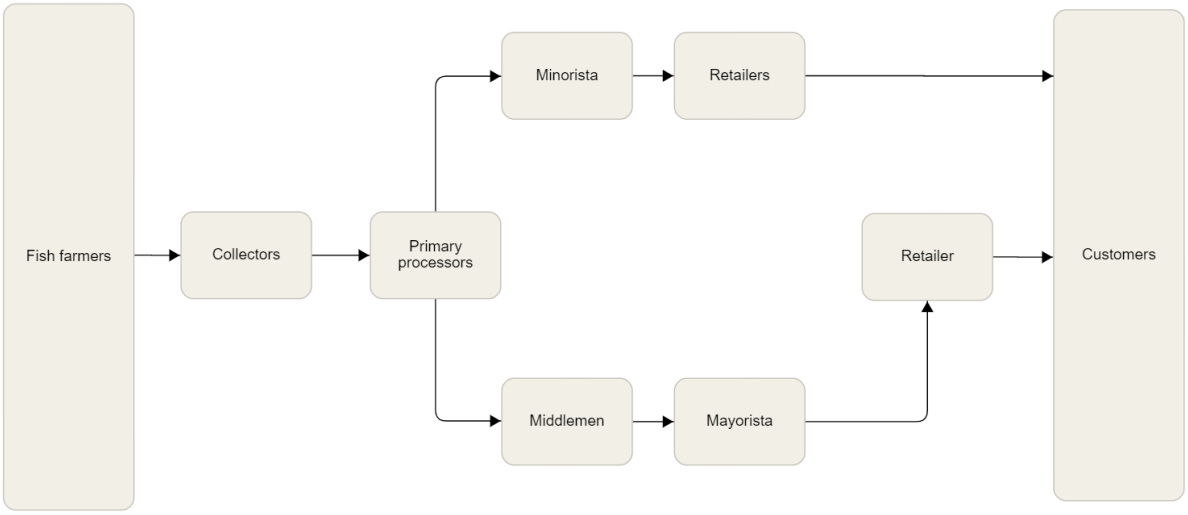
Organization dimension: this dimension technically explains how businesses are organized in detail to transform value. In FSC, the simplest form of organization structure is illustrated in the following Figure 3.5. Behind this long network of FSC, simply the main purpose is to deliver catch from the farmer to the end customers.

Figure 3. 5: FSC organization structure (Level 1)



Due to physical distances, product processing requirements and other regulatory issues, multiple intermediaries popped up in between the parties in this FSC. Detailed structure illustrated in the following Figure 3.6.

Figure 3. 6: FSC organization structure (Level 2)



BPM: Following Figure 3.7 captures the BPM of this FSC in detailed view including all relevant intermediaries in single model. Collectors, minorista, local seafood buyers, local wholesalers, mayorista are the main domestic intermediaries in the FSC. Through the assistance of processing manufactures, each intermediary adds little values to the products and charge higher price or earn commission fee when selling it for the next intermediaries. As customers increased demand for ready to cook in other words semi-finished products, multiple intermediaries have reason to stay in the market for a long time.

As show in the Figure 3.7, after catch passed through primary processing stage, it is either sold to minoristas, domestic minor commercial sellers, or local seafood buyers which more focused on selling high amount to further wholesalers. After continuation of this branch, once the catch are delivered at domestic central fishing market, they are either directly sold to domestic customers through retailers owned by local wholesalers or most high-end catches sold to mayorista who are major wholesalers controlling export markets. Destination countries, US, The EU, Hong Kong, China, impose very strict safety requirements, therefore, exclusive processing takes place right before catch loads to the shipping dock. Most luxury hotels and restaurants in this export markets preorder majority of the high-end catches. Some high-end and most low-end catches are ordered by wholesalers or seafood brokers to reach end customers.

Architecture dimension: Following Figure 3.8 shows party level architecture of FSC. In terms of relationship scenario, it is almost identical to architecture of BSC. The reason is, both cases want to sell products to both domestic and international markets and they are both distributed by two major suppliers in both categories, so that it is no wonder to see similarities. However, in this case, processing manufactures play significantly big role due to high standards of hygiene, customization and other preparation procedures demanded by all customers especially Western customers.

Therefore, processing manufactures maintain some way of connecting platform with customers directly, through labels, call centers and other means of communication.

Figure 3. 7: Business process model of FSC

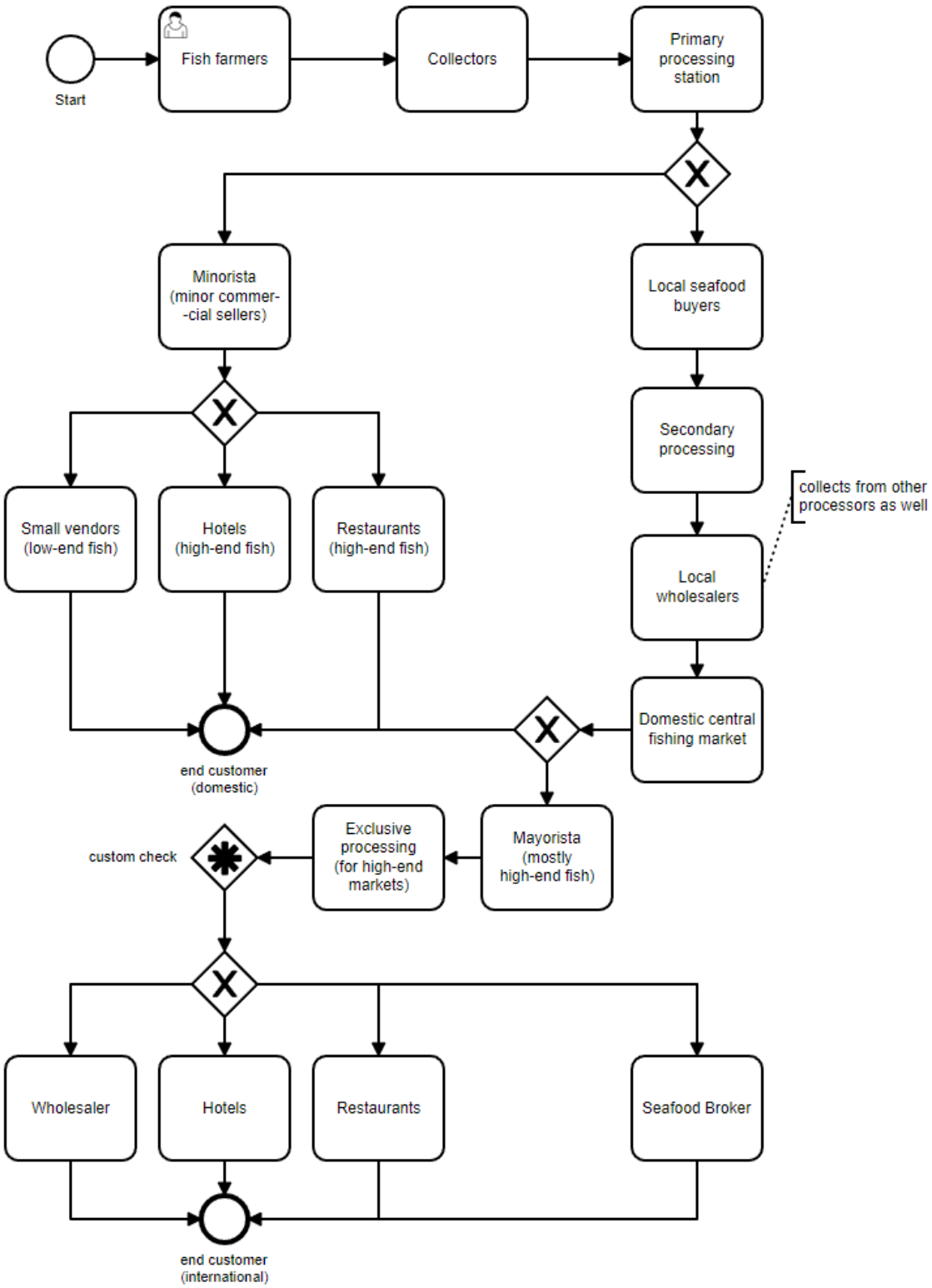
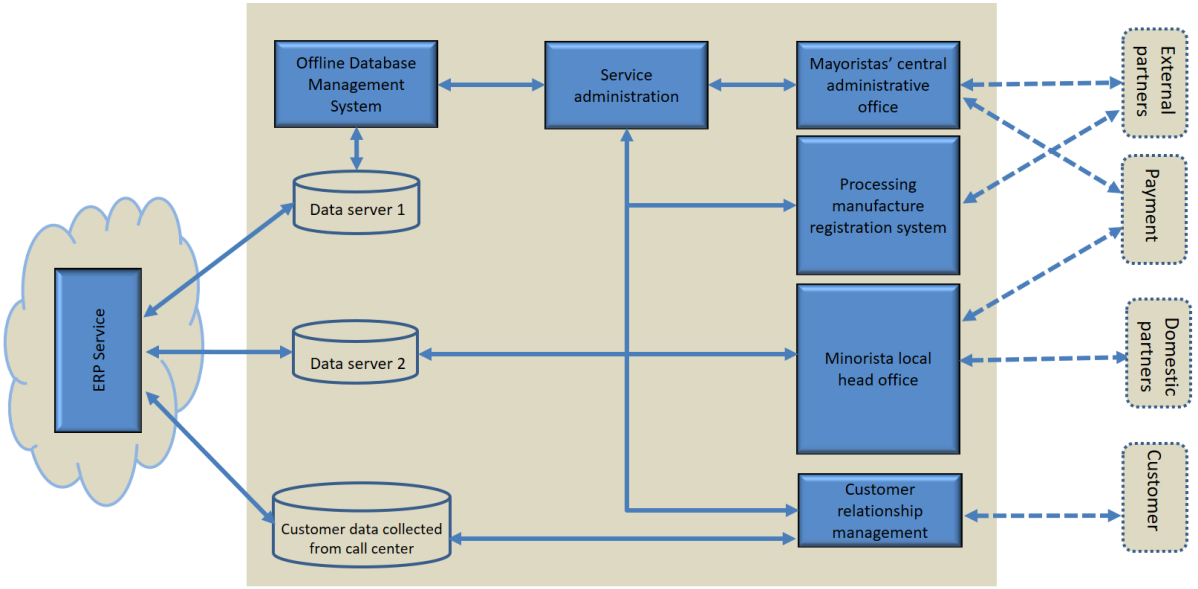


Figure 3. 8: Party level architecture of FSC



Technology dimension: In the case of FSC, parties use different small SCMS tools for their daily operation. Minoristas and local wholesalers use SCMS tools that allows mainly sales and order processing as well as logistics and distribution management functions. Similar to previous case, mayoristas are the main administrative point for managing international sales and logistics issues. Therefore, they use advanced SCMS tools with full functionality (customer-requirement processing, sales-order processing, distribution and inventory management, product receipt and supplier management/sourcing) to fulfill the demand of external partners.

Blockchain role in this part: Issue in this case is identical as previous case. Parties use different tools and there is no way of integrating them because it is costly and hard to maintain. Customer demand for transparency to retrieve product origin information is primary concern in this case. Therefore, integration of tools used by all parties is also the most primary issue as well.

Another big issue in this FSC is temperature control during shipment of the product. Seafood is one of the most sensitive and perishable product, so that providing safe shipment detail information is necessary nowadays.

Private blockchain solutions are recommended for this case due to high importance of internal auditing and transparency of cold chain. Private blockchain solution will fasten the transaction speed and increase the trust between parties as well as manage which participants will get permission.

For the development of system, we recommend parties in BSC to use currently available BaaS (Blockchain as a Service) tools to cut cost and save time. Cold chain modular solution of Food Trust developed by IBM Hyperledger is strongly recommended for this case. Parties in this FSC could purchase only appropriate modular solution without investing high price on full package.

3.3 Reference architecture development

We provide two types of main reference architecture solutions, basic and cold chain, based on knowledges accumulated from two case studies and number of Blockchain startup companies. Along with solutions, this study also provides full guidelines to inspire implementation design for successful BC solutions in FSC context. The guidelines include important requirements, components and quality attributes of BC solutions.

To build specifications/dimensions of the reference architecture, we have listed 24 Blockchain startup companies that are highly cited in the literature. We have chosen three dimensions (no of intermediaries, business drivers and business directions) from BOAT framework as most suitable and applicable in majority of real life cases. We also added three more dimensions (type of BC system solution, network and IOT devices) based on mutual knowledge found in most of the Blockchain startups. Each dimension is divided into two sub categories that represent main two options of the dimension. After all, 26 items including 2 cases, were tested under these major six dimensions. We give score 1 to cross sections which both dimension preference match with company's elements. For example: if blockfreight company provides services for enhancing CRM we give score 1 under dimension "enhanced CRM", so that we verify the value of this dimension. As a result, if total score of following dimensions exceed more than 20 (out of total 26), we define this dimension as solid dimension of reference architecture that fulfill the generalizability. If the total score is between 15 – 20, the dimension is considered as significant but questionable. If the total score is less than 15, we list it as not significant therefore it won't qualify to be the dimension of our final reference architecture.

Research articles in the literature concerning Blockchain implementation for supply chain either lacks contents or scale of the contents were limited to conceptual knowledge. Therefore, in the list of comparison we haven't included literature articles, instead we only tried to focus on current Blockchain supply chain startup companies because they were providing detailed solutions. White papers, published online articles, and website information are primarily used to draw information from these companies.

Knowledge from these findings not only helps to build reference architecture but also works as evaluation method since the findings are comparing the results of the RA dimensions.

Detail specifications are illustrated in the following Table 3.4.

Table 3. 4: Reference architecture modelling; comparison of startup companies and case studies

	Basic chain (B) /Cold chain (C)																							
	Number of intermediaries				Business drivers				Business directions				Preference in type of system solution				Preference in type of blockchain network				Preference in type of IOT devices			
List of Blockchain companies and cases	Preference in few (1-10)		Preference in more (>10)		Improve traceability & transparency		Expand markets geographically		Enhanced CRM		Fully automated operation		Preference in modular solution		Preference in integrated solution (full package)		Private blockchain		Public blockchain		Preference in reliable IOT devices (RFID, WSN)		Preference in basic IOT devices (Bar & QR codes)	
Type (Basic/Cold)	B	C	B	C	B	C	B	C	B	C	B	C	B	C	B	C	B	C	B	C	B	C	B	C
case 1 (BSC)	0	1	0	0	0	1	0	1	0	1	0	1	0	1	0	0	0	1	0	0	0	0	0	1
case 2 (FSC)	0	1	0	0	0	1	0	1	0	1	0	1	0	0	0	1	0	1	0	0	0	1	0	1
ambrosus	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	0	0	1	1	1	1
sweetbridge	1	1	1	1	1	1	1	0	1	1	0	1	1	1	0	1	1	1	0	0	1	1	1	1
waltonchain	1	1	0	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	0	0	1	1	0	0
shipchain	0	1	1	0	1	1	0	0	1	1	1	0	0	0	1	1	1	1	0	0	1	1	1	1
blockshipping	1	1	0	1	1	1	0	1	1	1	1	1	1	1	1	0	1	1	0	0	0	1	1	1
modum	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1
bita	0	1	0	0	1	1	0	1	1	1	1	0	0	1	1	1	1	1	0	0	1	1	1	1
everledger	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	0	0	1	1	1	1
300cubits	1	0	1	1	1	1	1	1	1	1	0	1	0	1	1	1	1	1	0	0	1	0	1	1
skuchain	1	1	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1
cryptowerk	1	1	1	1	1	1	0	1	1	1	1	1	1	1	0	1	1	1	0	0	1	1	1	1
monax	1	1	1	1	1	1	1	1	1	1	0	1	0	1	1	1	1	1	0	0	0	1	1	1
origintrail	1	0	0	0	1	1	0	0	1	1	1	1	1	0	1	1	1	1	0	0	1	1	1	1
tallysticks	0	1	1	1	1	1	1	1	1	1	0	0	0	1	1	1	1	1	0	0	1	1	1	1
blockfreight	1	1	1	0	1	1	1	1	1	1	1	1	1	0	1	1	1	1	0	0	1	1	1	1
circularise	1	1	0	1	1	1	0	0	1	1	1	1	0	1	1	1	1	1	0	0	0	1	1	1
provenance	1	1	1	1	1	1	1	1	1	1	0	1	1	0	1	1	1	1	0	0	1	1	1	1
blockverify	0	1	0	0	1	1	0	1	1	1	1	0	1	1	1	1	1	1	0	0	1	1	1	1
cargox	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	0	0	0	1	1	1
chainofthings	1	1	0	1	1	1	0	1	1	1	1	1	1	0	1	1	1	1	0	0	1	0	1	1
chronicled	1	0	1	1	1	1	1	1	1	1	0	1	1	0	1	1	1	1	0	0	0	1	1	1
mediledger	1	1	1	0	1	1	1	1	1	1	1	1	1	0	1	1	1	1	0	0	1	1	1	1
anyledger	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1
eximchain	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1
BASIC CHAIN	20		16		24		16		24		18		17		20		24		0		19		23	
COLD CHAIN		22		17		26		22		26		22		17		23		26		0		23		25

To give little detail of listed startup companies, we provide brief introductions of some big startups in the following.

Ambrosus

The international team of experts, Ambrosus, was one of the most successful ICOs in 2017, raising US$36 million. Ambrosus seeks to establish a system with less human interaction by building the hardware necessary to track items automatically via stickers and packaging that can be scanned for the relevant data. The Ambrosus network is a blockchain-based ecosystem for supply chains, ensuring the origin, quality, compliance and proper handling of items tracked by the network. Ambrosus' primary focus is on improving supply chains for life-essential products, specifically food and medicine, although the protocol can be applied to almost any complex supply chain.

Sweetbridge

International team of Blockchain experts from 10 different countries with 6 international branches is a technology stack and project alliance that solves four basic problems:

1. Lack of liquidity in supply chains, by creating an innovative collateralized liquidity economy;
2. Resource underutilization, by enabling asset sharing across organizational boundaries;
3. Suboptimal supply chain operations, by providing access to liquid professional talent and creating incentives for supply chain professionals to provide services based on objective measurements of outcomes;
4. Accelerating pace and scale of change, by creating more flexible and adaptive supply chains

Waltonchain

China-based startup Waltonchain (WTC for short) is a genuine, trustworthy and traceable business ecosystem with complete data sharing and absolute information transparency. It is created through a combination of the RFID and blockchain technologies, which pushes forward the blockchain + the Internet of Things integration.

Shipchain

LA-based startup mainly focused on tracking and transparency qualities of supply chain. Imagine a fully integrated system across the entire supply chain, from the moment a shipment leaves the factory, to the final delivery on the customer's doorstep; federated in trustless, transparent blockchain contracts. This is ShipChain. The ShipChain platform is based on a simple, yet powerful solution called "Track and Trace."

Modum

Swiss based company mainly focused on producing modum.io sensor devices which records environmental conditions while physical products are in transit. When a change in ownership occurs, the collected data is checked against a specific smart contract in the blockchain. This contract validates that the transaction meets all of the standards set out by the sender, their clients, or the regulator and triggers various actions: notifications to sender and receiver, release of goods, payment, etc.

Monax

Monax are pioneers of blockchain technology and were first to market with a permission able smart-contract capable blockchain design, Burrow. First of its kind when released in 2014, Burrow provides a modular blockchain client with a permissioned smart contract interpreter built in part to the specification of the Ethereum Virtual Machine (EVM). Monax's main product is a contract lifecycle management platform that uses blockchain, smart contracts and business processes to manage the contracts. The Monax Platform is a portal to the Agreements Network and will be launched late 2018.

300cubits

300cubits is international team of expert and is a blockchain initiative, looking to fundamentally change the container shipping industry through the creation of an industry-focused cryptocurrency called TEU tokens supported by a TEU Ecosystem. TEU is an industry acronym for Twenty-foot Equivalent Unit, a standard unit for containers. A TEU token is an ERC20 compliant digital token distributed on the Ethereum network and will be tradable on various cryptocurrency exchanges globally.

CargoX

Hong Kong and Slovenia-based CargoX is aimed to transform the global shipping industry by securing "Bill of Lading" documents using blockchain technology, thus providing a way for importers and exporters to exchange those documents digitally, securely and without counterfeit in an open environment. CargoX's goal is to disrupt the container shipping industry through the creation of decentralised and open protocols, tools and utilities for the exchange of shipment ownership (Bill of Lading) documents in the logistics industry

3.3.1 Reference architecture for basic FSC

FSC cases are generally divided into basic and cold chain in this thesis. Highly perishable food products are considered as cold chain FSC while other non-perishable (resistant to long-period shipment under room temperature) products are classified as basic FSC.

Based on comp suitability and requirements are organized in the following Table 3.5.

Table 3. 5: Suitable qualities for basic RA

Suitable FSCs for basic reference architecture implementation		
Parties	B2B	Parties in basic FSC exchanges goods and values with each other
Quality of objects sold in basic FSC	Both non-perishable or highly resistant to room temperature shipment	Canned goods, dry goods, dehydrated foods, ketchup, mustard, bottled water, etc.
Number of intermediaries in basic FSC	Few (1-10)	Few number of intermediaries (between 3 – 10) is ideal because we recommend private BC solution
Business drivers	Increasing efficiency (traceability & transparency)	All drivers are important; however, it is more suitable for FSCs that aim to improve operation efficiency
Business directions	Enhanced CRM	BC solutions improve customer's perception and increase their trust in the brand so that BC is suitable for FSCs that aim to improve CRM
Type of BC system solution	Integrated solutions	Although modular solutions are cheaper, integrated solutions are more reliable
Type of BC network	Private	Private blockchain with permissioned participants. For FSCs in general, faster transaction and controlled participants are important.

Type of IOT devices	Basic IOT devices (Bar & QR codes)	In BSCs, cutting cost is crucial therefore basic, well-know and cheap IOT devices are suitable

3.3.2 Reference architecture for cold chain FSC

Most of the fruits and fresh meat are the classic examples of perishable food. Products in our case studies are all perishable products. However, for banana case, temperature control of refrigeration during shipment is not as complicated as in FSC case. Bananas are usually stored with other perishable fruits or other products inside common reirrigating containers while fish requires special containers and more sophisticated temperature control. Following RA is designed especially for highly perishable products such as fish, other sort of meat, etc.

Other suitability and requirements are organized in the following Table 3.6:

Table 3. 6: Suitable qualities for cold chain RA

Suitable FSCs for cold chain reference architecture implementation		
Parties	B2B	Parties in basic FSC exchanges goods and values with each other
Quality of objects sold in cold chain FSC	Highly perishable and perishable (fruits; bananas, apples, etc.)	Fish is one of the most complicated perishable foods. Cheese, dairy products and eggs are other examples
Number of intermediaries in cold chain FSC	Few (1-10)	Smaller the number of intermediaries the better for the optimal efficiency
Business drivers	Increasing reach/efficiency (traceability & transparency, expand markets geographically)	Parties could take advantage of superior BC benefits to enter new markets. It is also beneficial for businesses that are aiming for efficient operation as well
Business directions	Completely automated business/Enhanced CRM	BC solutions improve customer's perception and increase their trust in the brand so that BC is suitable for FSCs that aim to improve CRM and their operation automation

Type of BC system solution	Integrated solutions	Although modular solutions are cheaper, integrated solutions are more reliable
Type of BC network	Private	Private blockchain with permissioned participants. For FSCs in general, faster transaction and controlled participants are important.
Type of IOT devices	Both reliable and basic IOT devices (RFID, Bar & QR codes)	For high-end products RFIDs are more efficient while many of the other transactions could be operated by basic IOT devices to cut cost.

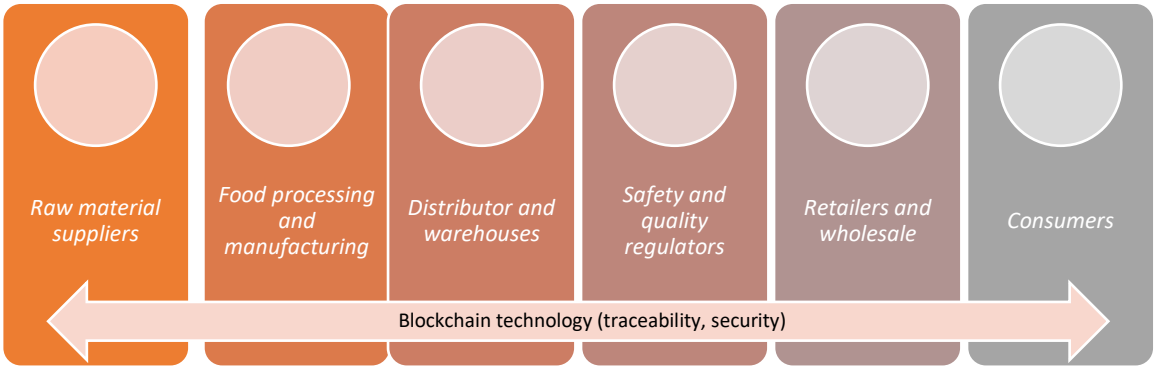
3.4 Components and requirements of smart food ledger RA

The idea behind applying Blockchain technology in food supply chain simply implies as shown in Figure 3.9. Primary objective of such implementation is to let Blockchain technology cover as much parties as possible throughout the entire supply chain. In many food business cases, its supply chain consists of different parties mentioned in sub-chapter below.

3.4.1 Food supply chain parties, components and duties

1. *Raw material suppliers* – growing corps, raising livestock, catching fish (farmer, herders, fishery, gardener, etc.)
2. *Food processing and manufacturing* – grading, processing, cleaning, slaughtering, manufacturing, packaging (manufacturer, factories, slaughterhouses, fishing dock, etc.)
3. *Distributor and warehouses* – packaging, delivering, classifying, quality checking, standardizing, tracking, storing (delivery companies, warehouses, storage hubs, etc.)
4. *Safety and quality regulators* – inspecting, grading, penalizing, licensing, standardizing (government food safety agencies, regional inspectors, etc.)
5. *Retailers and wholesale* – receiving, classifying, selling, storing, distributing, marketing (markets, supermarkets, wholesale stores, retail shops, etc.)
6. *Customers* – buying, returning, checking quality, reporting, consuming (local customers, group buyers, sole customer, etc.)

Figure 3. 9: Basic illustration of blockchain application in food supply chain

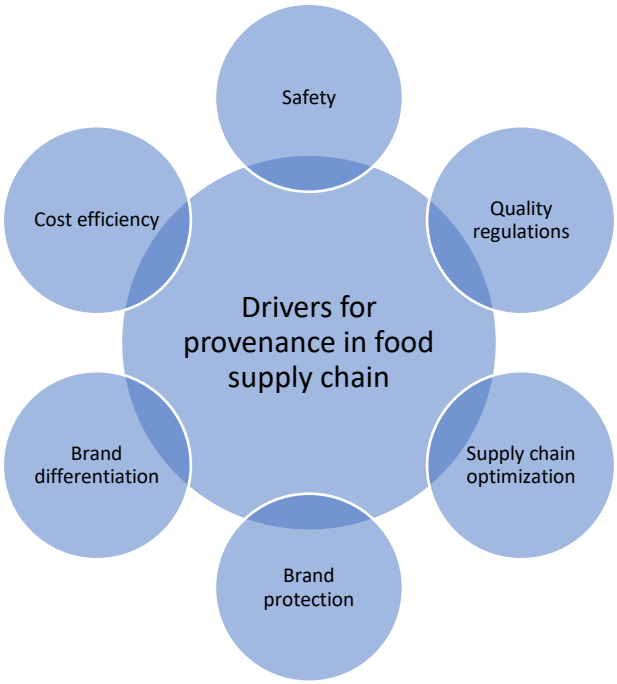


3.4.2 Drivers for provenance of food supply chain

To build reliable model for referent architecture, various number of requirements from numerous fields of businesses should be reflected. Depending on the business complexity and characteristics, some of the requirements are more magnetized, however missing to address important but frequently non-highlighted requirements leads to unrealistic modelling scenario. Before touching to the main system requirements, following part reflects the basic drivers why provenance and traceability is important in food supply chain.

Based on the proportion of demand from businesses, following six drivers stood out to be the top reasons and drivers for businesses to value traceability and provenance in food supply chain.

Figure 3. 10: Illustration of 6 drivers for provenance in food supply chain



1. **Safety** – prevent food accidents and protect society as well as account for responsible party.

2. **Quality regulation –** safety and quality management required by customers and regulatory offices
3. **Supply chain optimization –** faster, consistent and transparent process
4. **Brand protection –** prevention of brand image from incidents
5. **Brand differentiation –** increase brand image and quality and shift of brand category
6. **Cost efficiency –** reduce labor cost and safety-related process costs

3.4.3 Required qualities of smart food ledger management system

- BC network of supply chain management should be expansive enough to integrate all stages of parties
- To maintain smooth transactions of products and user interactions, it should provide an adequate user interface available for all parties in supply chain network
- To store real-time information about products, such as detail info about products, storage environment, receiving and delivering time of the products, etc. it should provide code reading function (RFID, Barcode, QR code reader, etc.)
- To support information management of users, it should provide simple/sophisticated (depends on the complexity of the business and technology-awareness of the users) information managing function
- To manage money transactions, it should have financing related function (connected through bank or other payment options).

3.4.4 Required components of smart food ledger

- Information transferring tags (RFID, Bar-code, QR code, etc.) - in most types of food products, tags are most likely the only option to be used to make the product traceable and accountable to the BC system. Depending on the product type, businesses decide what types of tags they should use. RFID is my personal recommended tag because it is easier to scan and more durable than other tags, however it is almost 5-10 times pricier than other types of tags (average 1 piece of RFID tag costs 50 cents while Bar-code costs 5 cents). For the products which customer are willing to pay little more for the safer condition, businesses could use RFID whereas Bar-code used for the less-cared food products such as; packaged cookies, candies, and gums, etc.
- Tag scanners - in most warehouses and shipping stations, both automatic scanners (i.e. big scanners at the gates of assembly lines) and mobile scanners (personally-used bar-code readers and RFID readers, etc.) should be needed. In cases of relatively small supply chain networks, smart phone scanning applications could be integrated to the BC system.
- Internet network (i.e. wireless network) at supply chain managing stations - tag scanners are required to be connected to network to update smart food ledger at real-time basis. For average

warehouses, installing wireless routers could be good solution. For small businesses where they use smartphone application to update BC network, they don't need of such network solution above.

3.4.5 General required qualities of smart food ledger architecture

- Completeness - it is one of the most important qualifications to build successful BC-supported food supply chain reference architecture. Completeness of the smart food ledger refers to business scale and how this model captures every part of business process. Smart food ledger should cover general guideline that can be used to build any types of supply chain model regardless of the business type, so that components of this reference architecture required to be complete.
- Feasibility - design of smart food ledger must be applicable in practice. As a general backbone of support, smart food ledger should have a clear blueprint and sound design. Specification of guideline should be precise not vague, and appropriability of usage in certain cases should be explicitly explained.
- Realistic - smart food ledger should be realistic and represent majority of real-life cases. Specifications of guidelines can't be exaggerated and should be fully explained if such thermology exists.

3.4.6 General food standards required by regulators

Table 3. 7: Food standards by regulators

Food standards by regulators			
Supply chain parties	**Recommended practice models**	**Globally accepted vertical standards**	**Globally accepted horizontal standards**
Raw material suppliers	GMP	ISO 9000 ISO 14000 ISO 22000 SQF QF	EurepGAP Feed Manufacturer Standard Propagation Material Standard, etc.
Food processing and manufacturing	GAP GMP		EurepGAP AmaGAP, ChileGAP, Mexico Supreme, Quality GAP, Naturane, Label Rouge, etc.
Distributor and warehouses	GDP GTP		COCERAL standards BRC Global Standards FPA-SAFE IFS Logistics Dutch HACCP
Safety and quality regulators			

Retailers and wholesale	GRP		COCERAL standards BRC Global Standards FPA-SAFE
Customers			

3.4.7 BC role in supply chain management system

Table 3. 8: BC role in supply chain management system

BC role in supply chain management system		
Supply chain parties	**Current management systems**	**BC-recommended management systems**
Raw material suppliers	• Food registration management	• All-in-one integrated single ledger solution to keep all records in same BC-supported platform • Each party in supply chain gets appropriate user interface solution from the system • Each party will be able to have an access (some might have limited access in private Blockchain ledger depends on the preference) to the main BC system • Input from all parties could be integrated in single ledger and be able shown to any parties (i.e. customer scans product and see all information inputted by all parties)
Food processing and manufacturing	• Food registration management	
Distributor and warehouses	• Cargo management • Delivery management • Product tracking management • Inventory management	
Safety and quality regulators	• Food standard management • License and quality certification management	
Retailers and wholesale	• Product registration management • Shelf management • Inventory management • Theft management	
Customers	• Customer profile management • Shopping management • Promotions management	

3.4.8 Comparison analysis of IoT devices used for product info

Table 3. 9: Comparison of IoT devices used for traceability

Technical instrument for traceability.

Technology	Description	Strengths	Weaknesses
Alphanumeric codes	Label which includes a sequence of numbers and letters of various sizes, Replaced by bar code	Simple to use and economic	Code read/write not automatic Poor performance High data integrity corruption No standards defined Lack of tie between different actors Cannot collect environmental information (no sensing capability)
Bar codes	Optical machine readable representation of data, Encodes alphanumeric characters and consist of vertical bars, spaces, squares and dots	Simple, more economical and exact traceability	Reading need line of sight Unreadable for damaged labels Can read one at a time by scanner Cannot collect environmental information (no sensing capability)
Radio Frequency Identification (RFID)	Detect presence of tagged objects, Identify or track using radio waves	No line of sight in reading, Can read and write tags Higher data rate and larger memory size Reversible tags, Can read many tags simultaneously	Rely on Reader for data collection, A tag cannot initiate communication, No cooperation among the devices, Can read data within one hop Cost still a burden Limited capability for environmental sensing
Wireless Sensor Network (WSN)	Collect sensing data from physical or environmental conditions, Variety of sensors available for sensing and monitoring	Multihop networking, In-network processing, Can deploy different network topologies, Secure communication among nodes, Longer reading ranges Sensor-actuator networking	Not suitable for identification purpose, Need energy saving techniques for continuous sensing

Based on past studies, we recommend using RFID devices for high-end products and highly perishable products in the cold chain FSC. RFIDs are in general can be scanned together and faster and relatively priced compared to its efficiency.

3.4.9 Comparison analysis of well-known Blockchain platforms

Based on our findings, none of the cases or companies are suggesting public blockchain for supply chain cases. Thus, from the Table below, we could suggest that Hyperledger Fabric and BigchainDB are two of the most frequently used platform. In terms of Hyperledger Fabric, they are not only well-known, but they recently provided their hands-on FSC application called, Food Trust.

Table 3. 10: Comparison of Blockchain platforms

Platform	**Ethereum**	**Hyperledger Fabric**	**IPFS / Filecoin / Storj**	**BigchainDB**
System type	public[4]	permissioned	public	Permissioned
Intended use	General purpose virtual machine, Smart contracts	Customizable blockchain framework for closed environments	Decentralized file storage	Decentralized document database
Data storage cost	High	N/A	low	low[5]
Database functionalities	no	no	no	yes
Suitable for highly interconnected data	no	no	no	no

Chapter 4

Case study evaluation for RA

The final chapter begins with BOAT framework analysis on the third case study of Mongolian meat trade. Further, case study is applied for RA solutions and brief discussion will follow. Next part introduces evolution method used in this thesis and local experts' evaluation on the case study will be discussed. Chapter concludes with general discussion for the entire study and conclusion.

4.1 Case study of Mongolian meat trade supply chain

In the case of meat trade in the capital city of Mongolia, unfair trade situations have been disappointed many consumers throughout the last two decades. Supply chain transparency is a key business challenge in this case. About 1.5 million people live in the capital Ulaanbaatar and according to National Statistical Office of Mongolia (NSO); total meat consumption is roughly 6 million livestock per year. Number of meat suppliers accounted for 311,373 by 2016, and they live in distant provinces (120km~1400km away) from the capital. To deliver meat supply to the capital, intermediaries so-called "ченж" (in Mongolian term) equivalent to "change" work as sub groups between meat supplier "herders" and "retailers" in the meat markets in the capital. Since intermediaries are the only ones who could control the physical meat supply, there has been many issues rose such as; price fixing, blockage of supply to create manipulated high demand to increase price, etc. The intermediaries work as group to lower competition in favor of their benefits and has been mastered to play on low bargaining powers of herders and the retailers. Due to harsh winter and lack of infrastructure, there hasn't been any efficient substitute solutions to this scenario. The government also hesitated to involve in this trade because they believe intermediaries earn very low profits from this situation therefore funding alternative solution is costly and unnecessary. As result of this, intermediaries still remain as in charge of this supply chain.

Challenges

Issues about current unfair trade and how such unfair situation developed are illustrated in the following two figures.

Figure 4. 1: **Problem scenario in Mongolian meat trade supply chain (20 years ago)**

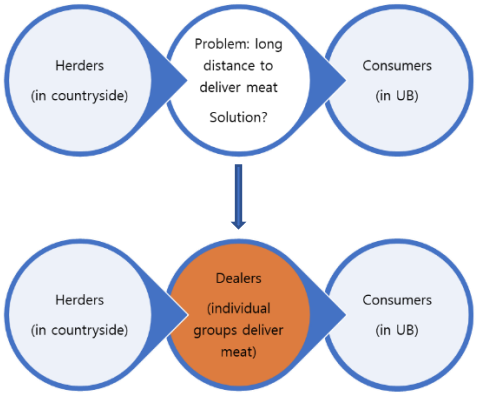
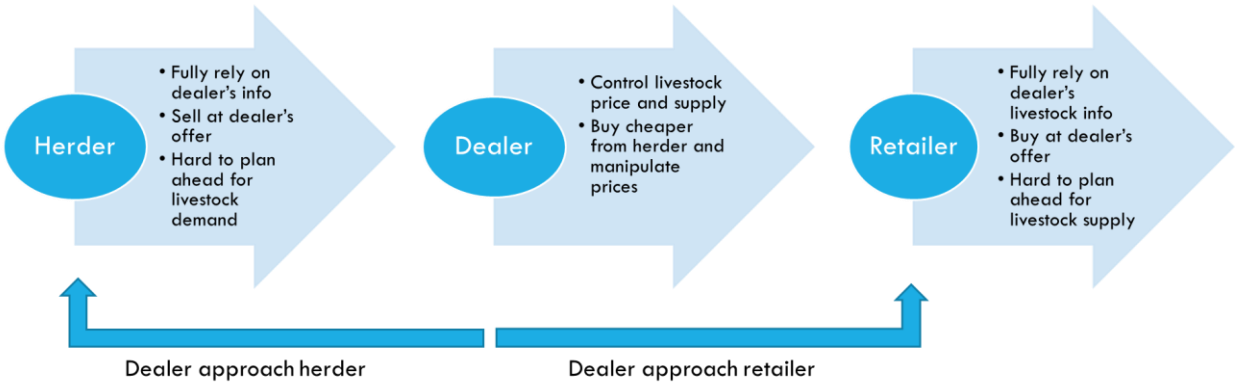


Figure 4. 2: **Problem scenario in Mongolian meat trade supply chain (current)**



Database in this supply chain trade doesn't exist. Only held by dealer if it does and not transparent

Business dimension: MMSC is B2B supply chain because essentially livestock are being exchanged between intermediaries for the value in this network. Sheep, goat, cow, horse and camel are the main tangible assets in MMSC. In terms of time scope, it is mainly semi-dynamic because majority of the dealers (mostly small groups) stay in this chain for a short period of time and leave the business due to harsh weather during winter and poor infrastructure. Although dealers make relatively high profits in this business because of their high bargaining power and price control, the operation of the business itself is hardship. A few of the big dealers in this chain operate steady and stay in the business for a long period of time.

In terms of drivers, parties in this chain don't have strong interest in expanding to international markets. Poor quality of processing industry and limited attention for infrastructure development such as damaged roads, limited gas stations, limited network reach, etc. disincentivize herders and dealers to actively pursue international markets. Therefore, current parties in this chain are more focused on improving the operational quality within domestic market. In terms of directions, parties in this chain

are willing to improve their current SCMS into faster and efficient one through adaptation of new technology. Due to recent increased pressure from customers for the quality and hygiene standards of the meat, parties start to take this matter more seriously. Functions of transparency and tracking are most important in this chain and they are open to welcome change.

Few years ago, majority of meat supply usually delivered by herders themselves to the capital from the farming land in faraway countryside. Due to difference in distances travelled, meat price was very inconsistent on the market. Delivery itself was a bothersome work for the herders. Middleman structure appeared back then, and it indeed improved the supply chain operation by increasing the total amount of meat supply and freeing herders from delivery duty by charging adequate commission fee. However, when MMSC starts to depend too heavily on the middleman, controlling power shifted only to middleman.

Overall business dimension classification is represented in the following Table 4.1:

Table 4. 1: **Business dimension of MMSC**

Case study: Mongolian Meat Supply Chain (MMSC)		
Parties	B2B	Parties in MMSC exchange livestock and values with each other
Objects	Physical goods (livestock, cattle)	Livestock, domesticated animals in the case, are physically exchanged between parties in the MMSC
Time Scope	Semi-dynamic, static	Due to harsh climate changes, parties in the MMSC are replaced periodically, only few ones become long-term partners
Drivers	Increasing efficiency/richness	Parties wishes to improve distribution efficiency. Due to high cost for maintaining hygiene standards, parties are not much interested in international markets
Directions	Integrated bricks and clicks /Enhanced CRM	Parties focus on improving current supply chain management system and open to adapt new technologies. Due to customer demands, optimization of SCMS for retrieving product information is primary concern

Networks	Deconstruction and reconstruction	MMSC had no stable dealers few years before. Herders themselves used to deliver meat to the capital. By adding dealer node connecting two parties, this MMSC is reconstructed
Structures	Demand chain	MMSC initiates through herders' livestock supply capability and customers' demand in certain number or type of livestock
Model	Producer	
Revenue stream	Margin on sales price of objects	

Organization dimension: simple essence of this MMSC is to deliver meat from herders to the capital. Such zoom out view is illustrated in Figure 4.3. Detailed view is shown in Figure 4.4.

Figure 4. 3: MMSC organizational structure (Level 1)

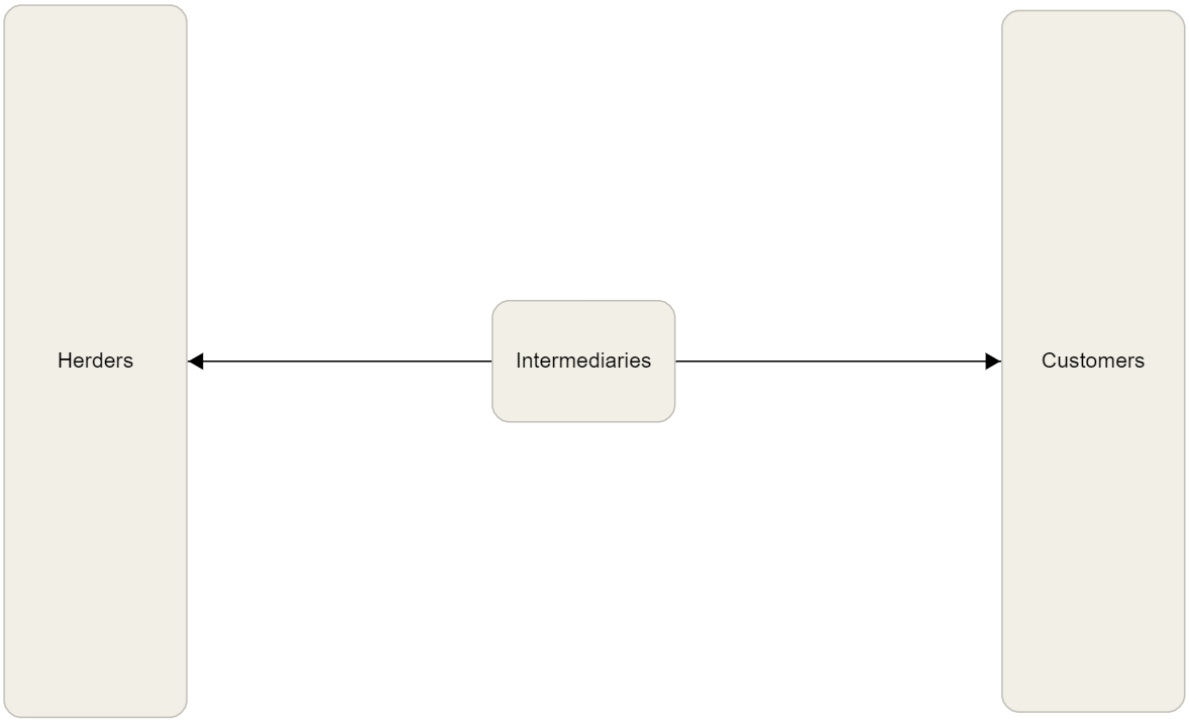
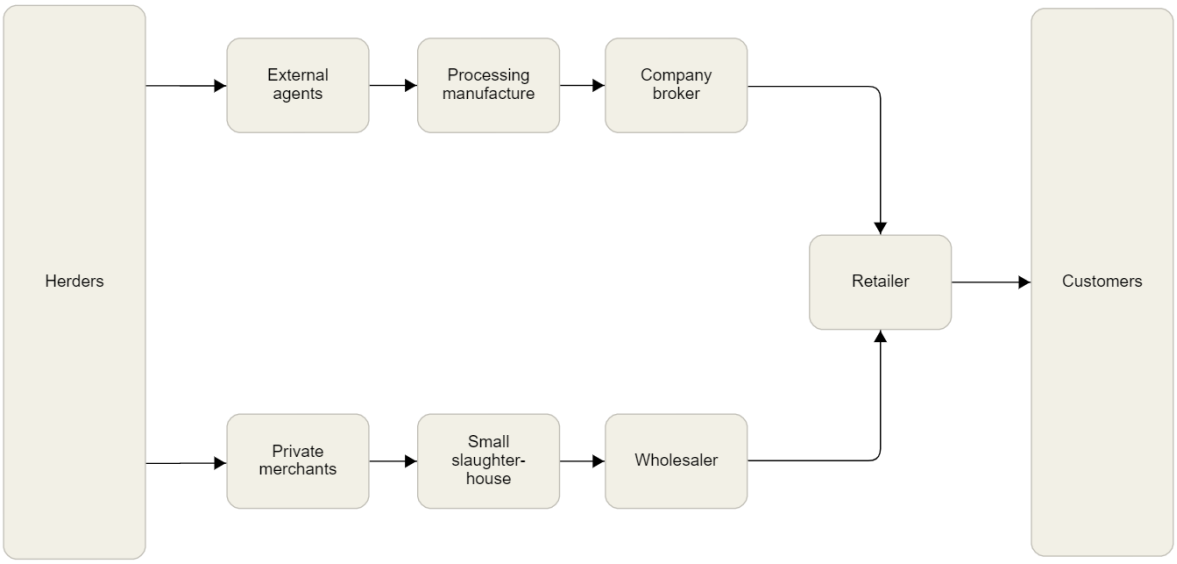


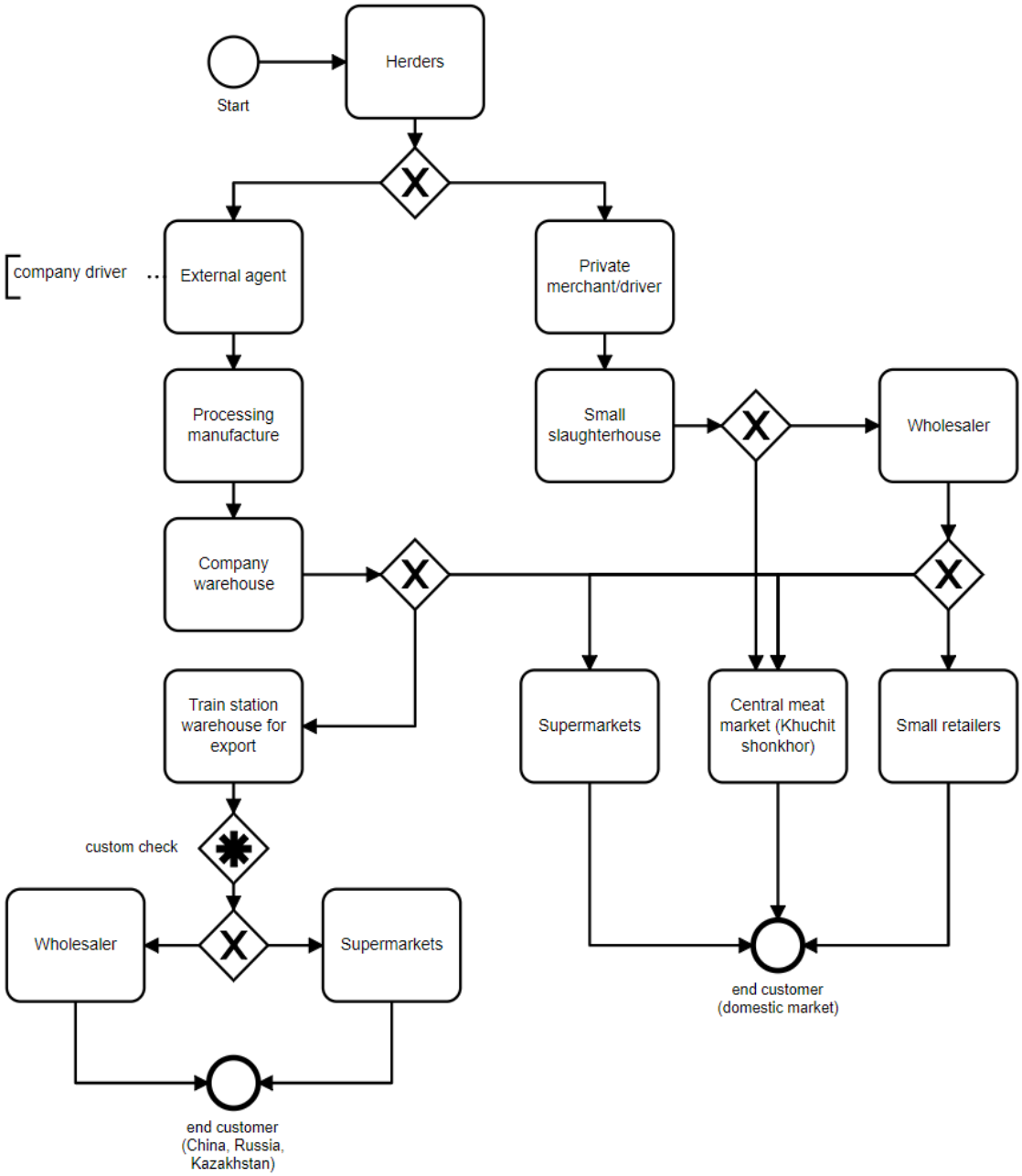
Figure 4. 4: **MMSC organizational structure (Level 2)**



BPM: Following Figure 4.5 captures the BPM of the MMSC in detailed view including all relevant intermediaries in single model. External agents (company), private merchants, and wholesalers are three main middlemen in this supply chain. Supermarkets, central meat market and small retailers do exist as intermediaries within domestic markets, however their added-price is significantly lower than the main three intermediaries mentioned earlier. Small slaughterhouses usually belong to herders in many cases therefore not much cost is spent on processing part when herders deal with private merchants. On the other hand, companies use their own processing manufactures to meet higher hygiene and quality standards required by international customers.

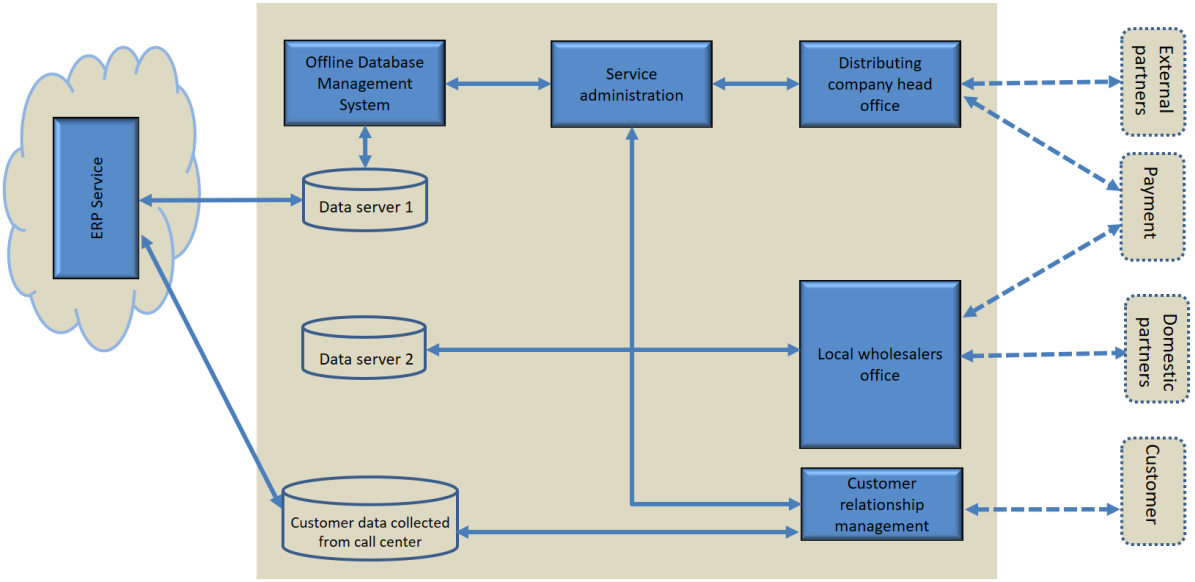
In general, company agents and private merchants physically deliver livestock from countryside to the capital. Once the livestock arrived to the capital, wholesalers and company brokers directly supply them to supermarkets, central meat markets (majority portion), and small retailers to eventually reach to the domestic end customers. Less than 10% of the total livestock are supplied to international markets such as; China, Russia and Kazakhstan, etc. Delivery goes through either train or by road (small portion) to reach international customers.

Figure 4. 5: Business process model of MMSC



Architecture dimension: Following Figure 4.6 shows party level architecture of MMSC. Overall relationship structure is similar to previous two FSC case studies. Although majority of meat trade goes through local wholesalers rather than private meat distribution companies, companies accumulate more database due to their technological power. Moreover, CRM collects relatively limited data due to lack of central offices aimed for CRM and less attention from the regulators in this network.

Figure 4. 6: Party level architecture of MMSC



Technology dimension: In the case of MMSC, local wholesalers use outdated trivial software to manage their operation although they are responsible for about 80% of the delivered meat to the capital. Quality of transparency and tracking function to origin is almost impossible using their software. In terms of meat distribution companies, they use multiple separate SCMS to manage their both domestic and international sales as well as logistics issues.

Blockchain role in this part: In zoom out view, customers receive meat sources from two different channels, wholesalers and company, in this case. However, these two uses separate SCMS tools and there is no way of integrating it. Although the original source of meat supplier, herders, provide same products, quality of product differs at arrival to customer due to different processing involved. Blockchain solution could be either separately adapted by two channels or there could be integrated solution involving both channels.

Domestic customers' concern on meat quality and safety wasn't so sensitive in the past, however, due to global trends and worldwide food incidents, customers started to increase their demand for transparency from intermediaries. The customers only demand most essential product information such as; origin of meat (which provinces are they from), quality certifications and slaughtered date, etc.

Private blockchain solutions with permissioned participants are recommended in this case. Details will be discussed in implementation part.

4.2 Reference architecture implementation for the case of MMSC

Livestock in this supply chain delivered to the customer as cattle (or by foot) or processed as slaughtered meat. Therefore, we recommend both basic and cold chain RA solutions to the parties in this case.

4.2.1 Basic RA solution

It will be adapted by intermediaries who manages cattle delivery between herder and retailers. Regardless of seasonal (winter and summer) weather challenges, the solution will enable intermediaries to work efficiently.

Table 4. 2: Suitability analysis for basic RA

Suitability analysis for basic solution			Case study
Parties	B2B	Parties in MMSC exchange livestock and values with each other	★
Quality of objects sold in basic FSC	Both non-perishable or highly resistant to room temperature shipment	Livestock by foot	★
Number of intermediaries in basic FSC	Few (1-10)	2-5 at most including chain of retailers	★
Business drivers	Increasing efficiency (traceability & transparency)	Parties in MMSC wishes to improve distribution efficiency	★
Business directions	Enhanced CRM	Due to customer demands, efficient software for retrieving product information is primary concern	★
Type of BC system solution	Integrated solutions	Integrated solution would be an issue due to high cost and lack of technology awareness. Modular solution is more suitable	
Type of BC network	Private	private blockchain with permissioned participants. It will allow faster transaction and controlled participants in the network.	★

Type of IOT devices	Basic IOT devices (Bar & QR codes)	Bar-coded cattle ear tags. It is efficient, simple and economical.	★

4.2.2 Cold chain RA solution

It will be adapted by intermediaries (wholesalers, companies, retailers) who manage processed meat delivery between herder and retailers. Once livestock processed to meat, it has shift to highly perishable good category. Cold chain is therefore straightforward solution in this case.

Table 4. 3: Suitable qualities for cold chain RA

Suitability analysis			Case study
Parties	B2B	Parties in MMSC exchange processed meat with each other	★
Quality of objects sold in cold chain FSC	Highly perishable and perishable (fruits; bananas, apples, etc.)	Processed meat	★
Number of intermediaries in cold chain FSC	Few (1-10)	2-10 including company's small distributors and chain of retailers	★
Business drivers	Increasing reach/efficiency (traceability & transparency, expand markets geographically)	If delivery and processing standards are possible to be increased, companies aim for more exporting markets. Parties also wishes to improve distribution efficiency.	★
Business directions	Completely automated business/Enhanced CRM	Due to customer demands, efficient software for retrieving product information is primary concern	★
Type of BC system solution	Integrated solutions	Integrated solutions will particularly improv efficiency of company agents and export market management	★

Type of BC network	Private	Private blockchain with permissioned participants. For FSCs in general, faster transaction and controlled participants are important.	★
Type of IOT devices	Both reliable and basic IOT devices (RFID, Bar & QR codes)	Although RFID tags are little pricier than Bar codes, efficient usage of RFID (single RFID tag on pallet, refrigerator, etc.) will cut cost and overall it allows smooth data management and distribution efficiency. Bar codes will be used for basic transactions	★

4.2.3 Possible implementation tactics

The effective integration between actors requires the integration of processes and information in the supply chain.

Proposed solution 1: To create separate regional offices that are mainly responsible for managing assets information from all parties and assist parties to update their transactions. The main reason of having these offices are due to lack of network connections in distant provinces, and lower technology adoptability of all parties. With the assistance of regional offices, herders can have digital profiles of their own along with their detailed livestock and financial assets information while retailers and intermediaries also can have digital profiles to access and share their needs in the ledger. This solution ultimately helps to create precise transparent database ledger, which all parties can access to the same information whenever and wherever they are. It secures the fairness of the meat trade between parties as well as the quality of the meat that ends up in customers' table. Such distributed, shared databases using Blockchain technologies offer highly secure and immutable access to supply chain data. *Proposed solution 2:* This solution could be implemented either replacing intermediaries as separate delivery companies or keeping intermediaries but letting them use Blockchain-enabled application throughout all transactions.

4.3 Expert evaluation

We recommend both basic and cold chain solutions for the MMSC case study. In this part, we report the expert evaluation for the suitability of RA solutions for MMSC. Not only solutions, we also evaluate whether proposed solutions fulfill recommended quality and requirements to be the optimal answer for success.

Local experts

It was challenging to find sufficient number of suitable experts for this study. Due to lack of local experts who has knowledge on both MMSC and blockchain, we ended up involving total of five experts. Four of them are from meat trade industry and last expert was from bank and finance. Among first four experts, two has been working in meat supply chain statistical office for over five years. They were able to access rare historical statistical information for MMSC and had adequate knowledge on Blockchain technology in terms of quality and advantages. Other two experts have worked as part of intermediaries over four and seven years respectively and able to provide realistic insights on the case evaluation. However, they had limited knowledge on the Blockchain concept only to extent to cryptocurrencies such as Bitcoin, Ethereum, etc. Fifth expert was long-term CFO in one of the largest banks and currently working as technology consultant in the finance field. The expert had rich knowledge on Blockchain qualities and enthusiastic about its potential in the future.

In-depth interview and questionnaire from industry experts

Although questionnaire was first stage, we decided in-depth interview would be more efficient because it allows rich discussion on this topic initially. Due to distances of interviewer and interviewee, interview held online through video and audio calls. After evaluation for general qualities of RA, we asked experts to fill out questionnaires which its questions only demand scaled answers on the qualities of RA. We used 9-point Likert Scale format for the answers.

Evaluation criteria

General opinion of experts on the Blockchain implementation in the MMSC were reflected during the interviews. Expert were asked to evaluate overall implementation of RA and type of solution selected was heavily discussed. To make our questionnaire simple and clear, questions were organized to find evaluation score on following qualities of the RA solution. For the system quality, we asked about completeness, modifiability, interoperability, integrability, security, and flexibility qualities of RA. For the architectural quality, we asked applicability, usability, feasibility, and automation qualities of RA.

Archival data

Database from National Statistic Office of Mongolia (NSO, http://www.en.nso.mn), was heavily used to analyze the historical statistical information regarding herders, volatility of price on meat products, and intermediaries. Major national news websites (news.mn, medee.mn, news.gogo.mn) were used to draw archival news about various changes in meat trade industry, such as; blockage of meat supply due to intermediaries, dramatic increase on meat demand, incidents related to intermediaries, etc. Other experts' interviews from those news websites and tv channels were also reflected. In overall, archival data contributed enormously to create better questions.

Evaluation results

In overall, experts were enthusiastic about the solution and usage of Blockchain in this RA. They do believe However, they were skeptical about realistic implementation of the solution. One of their biggest concern was cost issue. Although in case of modular solutions being purchased, they weren't convinced that market will shift to such BC-supported solutions. Another issue they have mentioned frequently was adaptability of technology to remote users who are not familiar with technologies. They recommended to add detailed technology awareness dimension in the RA.

Average scores from simple questionnaires are summarized in the Table 4.4. We expect feasibility quality took low score due to cost issue. Interoperability and usability issues are high likely result of immaturity of Blockchain technology in general and low trust in current developed software.

System qualities	Completeness	Modifiability	Interoperability	Usability	Feasibility	Automation qualities
Average score	7.8	7.6	5.6	5.4	5.2	7

4.4 Discussion

Potential barriers concerning the Blockchain-enabled application

Regulatory issues: technology, by definition, is not object of regulation, but the different uses of the technology is. Regulations have always struggled to keep up with advances in technology. There is thus a strong argument for Blockchain applications to work within existing regulatory structures not outside of them, but this means that regulators in all industries have to understand the technology and its impact on the businesses and consumers in their sector. The current regulatory landscape in Mongolia concerning Blockchain is obsolete, immature and complex, and it depends on what component of the Blockchain we are talking about; cryptocurrencies, shared ledgers, smart contracts, etc. The regulatory treatment of each of these components is different, although lack of specific regulation is a common

factor. Beside from meat trade, even regulation in cryptocurrency hasn't settled yet. Currently, the consideration from the point of view of taxation, and avoidance of illicit activities related to these cryptocurrencies are the first topics that have been addressed by policymakers and regulators. Considering cryptocurrencies from the point of view of taxation: some countries consider them as digital money, while others treat cryptocurrencies as digital products or commodities. Therefore, this immature regulatory system drawbacks the implementation of Blockchain-enabled applications in many industries. From the creator's perspective, we should focus on these questions to smoothly implement the application.

How do current regulations impact our application of Blockchain in this supply chain?

Where are current regulations lacking?

What will a regulator want to know about our application?

Cultural issues: A Blockchain represents a total shift away from the traditional ways of doing things – even for industries that have already seen significant transformation from digital technologies. It places trust and authority in a decentralized network rather than in a powerful central institution. This brings loss of control from some and such dramatic changes impact current settled culture and organizational structure. It has been estimated that a Blockchain is about 80% business process change and 20% technology implementation. This means that a more imaginative approach is needed to understand opportunities and how things will change on current platform. Following two questions would be most concerning to evaluate the changes and tackle this issue.

Who will be most affected by Blockchain implementations and are they supportive?

Which areas of our business are likely to be most disrupted?

Security and privacy: Many potential applications of the Blockchain require smart transactions and contracts to be indisputably linked to known identities, and thus raise important questions about privacy and the security of the data stored and accessible on the shared ledger. Although no one has yet managed to break the encryption and decentralized architecture of a Blockchain, except for few incident hacking incidents regarding Bitcoin, security of this technology is still not widely considered to be 100% safe at least to the major crowd. In particular, driving public acceptance of Blockchain applications will likely mean proactively framing the discussion of privacy around concepts of value, security and trust. To increase this awareness, I believe time and wide implementation of the application itself would help. Following are concerning questions to tackle the issue

How are we applying security to our application and is privacy a priority?

How are we engaging with our customers?

Have we thought about what our customers think about our application beforehand?

Awareness of technology: The principal challenge associated with Blockchain is a lack of awareness of the technology, especially in sectors other than banking, and a widespread lack of understanding of how it works. This is hampering investment and the exploration of ideas. For example, as George Howard, contributor to Forbes Media and Entertainment says about the music business, "Artists – visual, musical, or otherwise – really must educate themselves about these emerging technologies or suffer the fate of being exploited by those who do". This applies in other areas as well. In more wider sense, there must be some educational programs should be considered in order to provide reliable information about Blockchain technology. Following questions are considered for this issue

Who is a thought leader in this industry in Blockchain technology? Who should people listen to?

How do we increase people's level of understanding – at all levels?

As a conclusion, we could say that there are many opportunities as well as many challenges arise from the implementation of this emerging technology called Blockchain. It has said to be disruptive, yet we haven't fully realized its disruptiveness in many industries. Therefore, it is early for organizations or governments to be scared and rather people should smoothly invest their time to understand this technology first before judging to accept it. Many challenges mentioned above are the potential expected ones thus they may not be real challenges in the reality. Finally, it is important to keep positive attitude to these new promising technologies, because it is easy to be left behind from the fruitfulness of the new technology if we always reject to new ideas.

Conclusion

First, this thesis successfully analyzed three case studies, one real-life and two fictitious, with the help of BOAT framework. From the collected knowledge in four dimensions of BOAT analyses, each case study was shaped in a way to its unique quality and were able to provide clear categorical findings to the development of RA. We believe overall knowledge accumulated from only case studies itself has become truly useful insight in the literature.

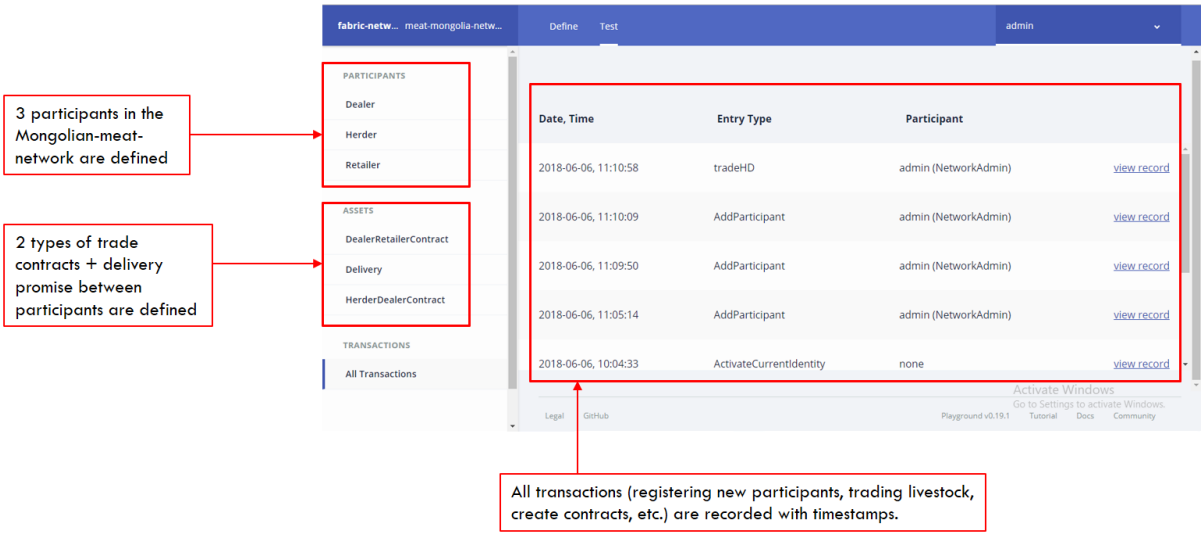
Based on rich findings of the case studies and few past studies, we successfully built two types of smart food ledger RA; basic and cold chain. During the development of RA, it was observed that case studies furnished interesting insights through its analyses of challenges, characteristics and consumer preferences. In general, we defined that RA architecture solutions should differ essentially of food's perishable quality. Highly perishable food products such as, seafood, beef, dairy and vegetables and fruits, etc. require discreet shipment procedures, therefore mature and sophisticated SCMS plays a big role. As such, we reflected comparable attributes in the specification of our cold chain RA solution. In a way of design interpretation, cold chain RA could be considered as level two of basic RA solution. However, basic RA solutions itself is independent in a way that it provides economical decision-making powers and suggestion of efficient solution type.

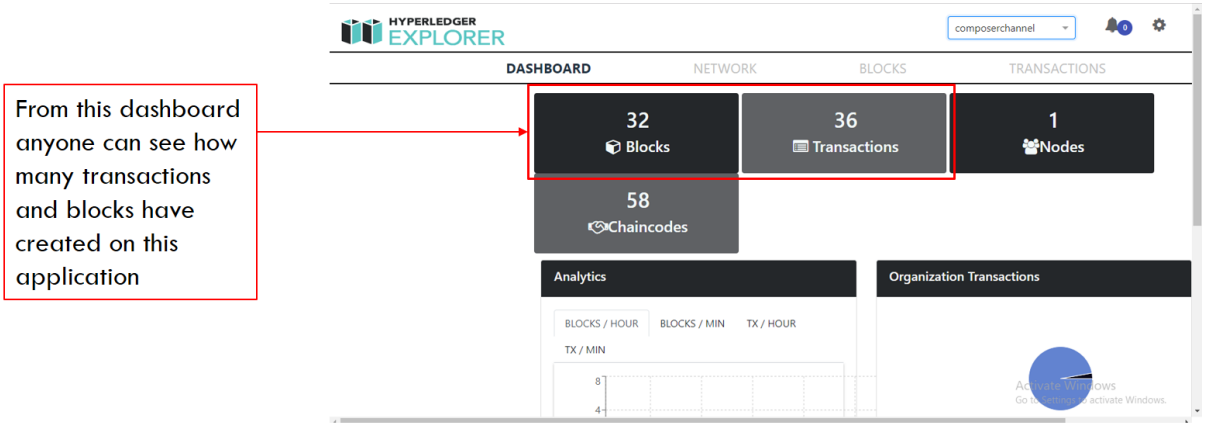
In chapter 4, with the help of five local experts, we evaluated our third real-life case study which adopted both basic and cold chain RA solutions. After in-depth interviews and simple questionnaires, we found that proposed RA solutions are not perfect, however, there are possibilities to improve in terms of its system and architecture qualities. Since Blockchain applications are still in its premature stage and mainstream adaption is far away, we face numerous challenges not only in technical aspect but in cultural, technology awareness and government regulation.

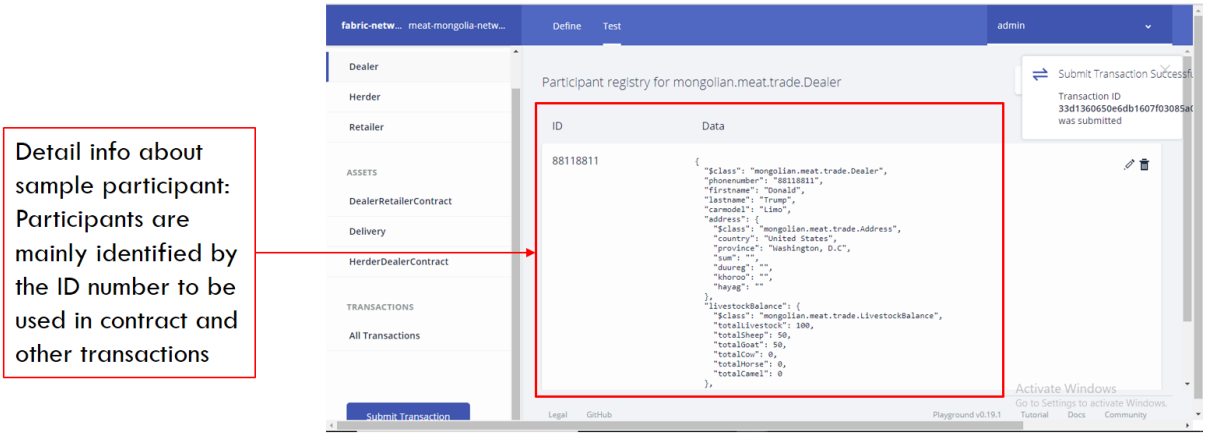
Finally, we believe this study has achieved its objectives at some levels especially by expanding lacking literature with Blockchain implementation contributions.

Appendixes

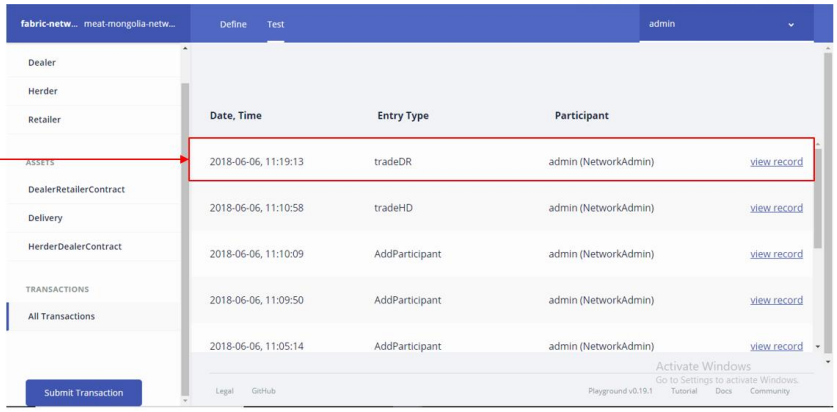
Hyperledger demo solution for MMSC



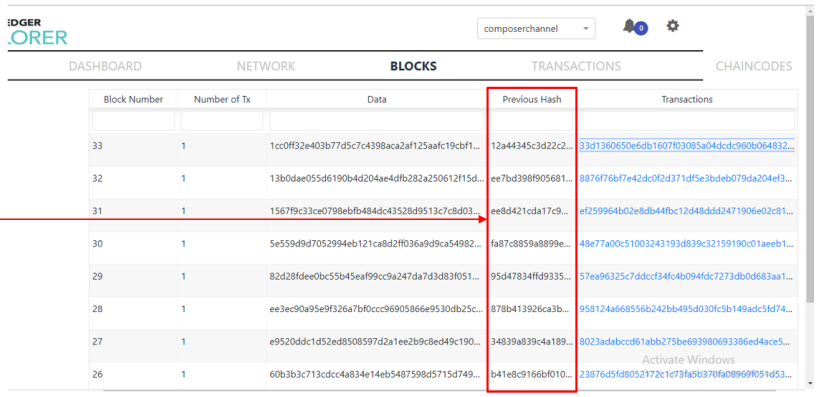




New transaction added



Blocks are secured by unique hash



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