Development of a Reference Architecture for the Design of Tracking and Tracing Solutions in the Supply Chain using Blockchain Technology

By

Wilhelm Nicholas Louw

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Supervisor: Prof. Louis Louw

Co-supervisor: Prof. Daniel Palm

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Declaration

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Abstract

This masters thesis involves the development of a design reference architecture for the use of blockchain technology in the supply chain. It aims to further the research on blockchains' use and development, specifically with regards to tracking and tracing.

Blockchain is a revolutionary new technology, capable of disrupting today's supply chains. Originally envisioned for finance, the technology behind the Bitcoin cryptocurrency, blockchain can maintain an immutable, secure and trusted record of transactions between a network of individuals, who do not necessarily trust one other. This makes it highly applicable to supply chains as it can enable the secure sharing of information between different parties. Supply chains are facing problems due to a lack of information transparency and trust. Traditional supply chains contain a combination of paper-based processes and digital systems, where information is held up in 'silos'. Lack of end-to-end process integration and information sharing, results in problems regarding tracking and tracing of products. Tracking and tracing is key to digital supply chains as changing consumer behaviour and market conditions demand higher supply chain visibility. Traditional methods are, however, slow, fragmented and ineffective. This makes it problematic to validate a products origin, location or specific characteristics.

Blockchain has the potential to facilitate trust and enable end-to-end supply chain visibility. A lack of academic research has caused a paucity of knowledge on the use and implementation of blockchain in the supply chain. Supply chain companies do not understand blockchain, including the various aspects involved in its design. There are currently no identified frameworks, models or architectures that aid in supporting its use in supply chain applications.

The main aim of this project is to construct a reference architecture that can support the design of blockchain in the supply chain. Reference architectures define recommended practices and guidelines, that are used as a frame of reference to improve the quality, speed and cost of the information modelling process.

Blockchain technology was investigated, its latest technological architectures were identified and its role in supply chain digitalization was defined. Aided by existing reference architectures, a methodology was formed for designing a blockchain reference architecture. The important blockchain design requirements were identified and extracted from blockchain frameworks, case studies and technical architectures. The design reference architecture, for the use of blockchain technology in the supply chain, was constructed. It contains the relevant design guidelines relating to strategy, feasibility, technology, supply chain and product sub-components. It serves as a guide that can be consulted by companies in order to aid decision making.

A practical case study application in the FMCG foods supply chain, along with semi structured interviews with industry experts, tested the validity and practicality of the reference architecture. The results motivated that the architecture formalized a collection of knowledge, aiding in the understanding and effective decision making, of blockchain in the supply chain. The design reference architecture furthers knowledge on the application of blockchain technology in the supply chain, and provides a basis for future research and development.

Opsomming

Hierdie meesterstesis behels die ontwikkeling van n ontwerp-verwysingsargitektuur vir die gebruik van blokketting-tegnologie in die voorsieningsketting. Die projek se doelwit is om die navorsing en gebruik van blokketting-tegnologie in die voorsieningsketting te bevorder, met spesifieke klem op die naspeurbaarheid van produkte.

Blokketting, n rewolusionêre nuwe tegnologie met die potentisiaal om die huidige voorsieningskettings te ontwrig, is oorspronklik ontwikkel vir finansiele toepassings, as die tegnologie waarop die Bitcoin kriptogeldeenheid gebaseer is. Blokketting het die vermoë om n onveranderlike, veilige en betroubare rekord van transaskies te behou, tussen n network van individue wat mekaar nie noodwendig hoef te vertrou nie. Dit beteken dat hierdie tegnologie die geleenthied skep vir volle naspeurbaarheid binne enige voorsieningsketting. Huidige voorsieningskettings ervaar probleme as gevolg van n gebrek aan inligtingsdeursigtigheid en vertroue. Tradisionele voorsieningskettings gebruik ń kombinasie van papier-gebaseerde prosesse en digitale stelsels, wat veroorsaak dat inligting in 'silos' vasgehou word. Die gebrek aan gedeelde inligting, veroorsaak probleme met die naspeurbaarheid van produkte. Naspeurbaarheid is n belangrike komponent van digitale voorsieningskettings, aangesien dit die deursigtigheid van informasie kan verseker. Huidige naspeur metodes is stadig en ondoeltreffend. Dit bemoeilik dus die bevestiging van die oorsprong en kwalitiet van produkte.

Blokketting het die vermoë om vertroue in sovel as deursigtighied van die voorsieningsketting te bewerkstellig. Daar is tans ń gebrek aan akademiese navorsing rondom blokketting-tegnologie wat lei tot ń gebrek aan kennis oor die gebruik en implementering daarvan in die voorsieningsketting. Daar is tans geen geïdentifiseerde raamwerke, modelle of argitekture, wat die gebruik daarvan in die voorsieningsketting ondersteun nie. Die hoofdoel van die projek is om ń verwysingsargitektuur te bou wat die ontwerpproses van blokkettingstelsels kan ondersteun. Verwysingsargitekture bevat aanbevole praktyke en riglyne wat gebruik kan word as n verwysing om die gehalte, spoed en koste van ń inligtingstesel ontwerp te verbeter.

Die blokketting-tegnologie is nagevors, die nuutste tegnologiese argitekture is geïdentifiseer en die rol daarvan in voorsieningsketting-digitalisering is omskryf. Met behulp van bestaande verwysingsargitekture, is n metodologie ontwikkel om n blokketting verwysingsargitektuur te ontwerp. Die belangrike vereistes vir die ontwerp van ń blokketting stelsel geïdentifiseer is vanuit navorsing oor huidige blokketting raamwerke, gevallestudies en tegniese argitekture. Die ontwerp-versysingsargitektuur vir die gebruik van blokketting-tegnologie in die voorsieningsketting is gebou. Dit bevat relevante ontwerp riglyne met betrekking tot strategie, tegnologie, uitvoerbaarheid, voorsieningsketting en produk komponente. Dit dien as n gids wat deur ondernemings geraadpleeg kan word om besluitneming te ondersteun. ń Praktiese gevallestudietoepassing in die voedselvoorsieningsketting, tesame met semi-gestruktureerde onderhoude met kundiges in die bedryf, het die geldigheid en praktiese toepassing van die verwysingsargitektuur getoets. Die resultate motiveer dat die argitektuur die nodige inligting bevat wat bydrae kan lewer tot beter begrip en doeltreffende besluitneming van blokketting-tegnologie in die voorsieningsketting. Hierdie ontwerp-verwysingsargitektuur bevorder kennis oor die toepassing van blokketting-tegnologie in die voorsieningsketting, en bied n basis vir toekomstige navorsing en ontwikkeling.

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List of Acronyms

AI	Artificial Intelligence
DLT	Distributed Ledger Technology
DPOS	Delegated Proof Of Stake
DRA	Design Reference Architecture
ERP	Enterprise Resource Planning
FMCG	Fast Moving Consumer Goods
GM	Genetically Modified
IoT	Internet of Things
PBFT	Practical Byzantine Fault Tolerance
POS	Proof Of Stake
POW	Proof Of Work
RFID	Radio-Frequency Identification
RQ	Research Question
SC	Supply Chain

Glossary

Bitcoin	Bitcoin is the most well-known cryptocurrency in existence.
Blockchain	The technology underpinning the cryptocurrency, Bitcoin. Blockchain consists of a record of cryptographically secure transactions, maintained across several interlinked computers in a peer-to-peer network.
Consensus Mechanism	A fault-tolerant mechanism that is used to form an agreement on a single data value or system state among a distributed network of participants.
Cryptocurrency	A decentralized digital currency that operates without a bank, or central administrator, and can be sent from user to user on a peer-to-peer network.
Digitalization	The adoption of digital technologies for increases in efficiency and effectiveness.
Distributed Ledger	A database that is shared and synchronized across multiple locations and, institutions. Contains a decentralized list of transactions that is publicly visible.
Ethereum	A public, open source blockchain platform and operating system with smart contract functionality.
Fast Moving Consumer Goods	Fast Moving Consumer Goods are products that are sold quickly and at relatively low costs. It includes household goods such as packaged foods, beverages, personal and home care products.
Hyperledger	An umbrella project of private blockchain platforms and related tools.
Industrie 4.0	The trend towards automation of data exchange in manufacturing technologies and processes, which include cyber-physical systems, IoT, cloud computing and AI. Also referred to as smart factory or smart manufacturing.
Internet-of-Things	IoT refers to a system of interrelated devices, objects and machines that have the ability to communicate with each other and transfer data over a network without requiring human-human or human-computer interaction.
Node	A node is a computer that participates in the blockchain network.
Reference Architecture	Reference architectures are predefined models of recommended practices that are used as a frame of reference, and as such can improve the quality, speed and cost of the information modelling process.
Supply Chain	A network of all the activities, people, resources, information and organizations involved in the creation and sale of a product, from raw materials to the consumer.
Tracking and Tracing	The ability to monitor products throughout the supply chain by recording information about its identity along the way. It allows for different actors to verify information such as a products origin, history or quality.

Chapter 1
Introduction

1.1 Background and rationale of the research

In 2008, an anonymous individual, under the pseudonym Satoshi Nakamoto, published a whitepaper titled '*Bitcoin: A Peer-to-Peer Electronic Cash System'*. It detailed a new technology that allowed a secure method of sending peer to peer electronic transactions without the need for a 3rd party or middleman (Nakamoto, 2008). This meant that a person could instantly engage in a secure financial transaction with any person, anywhere in the world and without the need to use a financial institution. As revolutionary as this process was, for the next few years, Bitcoin would remain largely under the radar, limited to the early fringes of the technology life cycle. It wasn't until 2017 when a rapid increase in the value of bitcoin, brought it into the spotlight of mainstream attention. In one year its value increased from R15 000/bitcoin to over R250 000/bitcoin, which, in turn, sparked a worldwide interest in cryptocurrencies (CoinDesk, 2019). Today there are thousands of different cryptocurrencies in existence. These cryptographically secure digital assets work as a medium of value exchange and can be used as an alternate to traditional currency. A few years after the launch of Bitcoin, entrepreneurs and early pioneers began taking an interest in the technology underpinning bitcoin called blockchain technology. If this technology can allow untrusted individuals to engage in trusted transactions, whilst maintaining an immutable ledger, across a network of participants, all without the need for central authority/control, then it has the potential for many other disruptive applications.

Today, the value of bitcoin has significantly dropped. Experts have divided opinions on cryptocurrencies, some proclaiming them to be the financial system of the future, whilst others define them as mere speculation with a currency of no real world value. As much as it is promoted, there appears to be no consensus on the future value of cryptocurrencies (IntelligenceSquared, 2018). Blockchain technology however, is described as one of the key new technologies of the 21st century. It has the potential to drive disruption and deliver a significant amount of value across a variety of industries (Gartner, 2019). Along with technologies such as Artificial Intelligence (AI) and the Internet-of-Things (IoT), blockchain has become one of the key drivers of digitalization and Industrie 4.0, technology movements where networked processes and products will interact without human control to form complete digital ecosystems (Ivanov, et al., 2019; Schrauf & Berttram, 2016).

Over the last three to four years, businesses and industries have come to realize the potential benefits that the technology offers. More than a third of organizations have started adopting blockchain and a recent study estimates the total blockchain technology market size at $57 Billion by 2025 (Treiblmaier, 2018; GrandViewResearch, 2019). The revolutionary advantages of blockchain has led to the technology experiencing incredible amounts of hype, even to the point where adding the word '*blockchain*' to a company's name, could cause its shares to surge (even though the company had nothing to do with blockchain) (Bloomberg, 2017). It was only realized, after industries have invested billions of dollars, that there was a severe lack of applied and academic research supporting its development (Treiblmaier, 2018). The result is that there has been few successful real world applications of blockchain. There is a paucity of knowledge regarding where and how blockchain will be effectively applied and the only way to overcome this is by conducting research into its properties, characteristics and specific areas of application (Risius & Spohrer, 2017; Zile & Strazdiņa, 2018).

The opportunity to be at the forefront of an exciting new technology sparked the initial interest in this masters study. Being able to make sense of a complex, disruptive technology and contribute to its development was a large motivator in undertaking this research process. After conducting initial research, it was found that, besides finance, one of the most promising areas of application for blockchain technology is in the supply chain (Kshetri, 2018). Blockchain's ability to keep an immutable ledger of transactions across a network of untrusted participants has been determined as a key capability for supply chain traceability. That is, the ability to identify and trace the history, distribution, location and application of products and materials to ensure the reliability and sustainability of claims (Kairos Future, 2017).

Traceability is an integral part to supply chain digitalization and is seen as the main use and application of blockchain in the supply chain. It is especially applicable in food supply chains where it can help validate health and environmental claims and aid in countering food related disease outbreaks (Kshetri, 2018). Early case studies and pilot projects have yielded incredible results, with some shortening the ability to trace a products history from seven days to just two seconds (Hyperledger, 2018). However, there is yet to be a successful full scale deployment of blockchain in the supply chain.

There is currently very little research dedicated to the implementation of blockchain in the supply chain. The mismatch between blockchain supply chain investments and general research and application knowledge is bound to lead to failed use cases and disappointment. Almost all blockchain supply chain research indicate the need for further studies into its application and implementation (Zile & Strazdiņa, 2018; Yli-Huumo, et al., 2016). This masters project will aim at developing a reference tool that can be used to help guide supply chain companies in the design of blockchain supply chain systems. Such a tool will be valuable for the understanding and further advancement of a technology that is bound to have significant impact, and the ability to disrupt supply chains worldwide.

1.2 Problem statement

1.2.1 Problem formulation and background

Today's supply chains contain a combination of manual, paper-based processes and digital systems (Lo, et al., 2017). Traditional supply chains, and especially their IT systems, are often described as being '*silos*' according to the '*silo and ecosystem*' supply chain model (Capgemini, 2011; Lo, et al., 2017; Deloitte, 2019; Schrauf & Berttram, 2016). This implies that they are separate, free standing structures with little interlink between them. This hinders the sharing of information between parties and results in issues such as lack of traceability and transparency across the entire supply chain.

Increased developments in new technology and changes in the market and consumer behaviour have, among other factors, resulted in an increased focus on supply chain's need to provide transparency with regards to the products they offer, according to the 2019 global consumer insights survey (PWC, 2019). Future success of the next generation of supply chains mean they will have to rely on the ability to operate more like ecosystems, as opposed to silos (SAP, 2018). The key capability here, is for supply chains to efficiently share and exchange information. Traditional supply chains are filled with friction, caused primarily by a lack of complete and timely information (Schrauf & Berttram, 2016). This is why the overreaching goal of supply chain digitalization is to open up the supply chain network for all to see. One of the main drivers in this endeavour is the tracking and tracing of products throughout the supply chain.

An area where this is especially applicable is with food supply chains, where many of the current problems are tied to a severe lack of transparency and accountability between companies (Kshetri, 2018). Food supply chains are complex and involve a multitude of stakeholders such as farmers, factories, distributors, suppliers, retailers and consumers. Currently, with traditional supply chain processes, an information asymmetry exists between stakeholders which hinders transparency and leads to mistrust (Mao, et al., 2018; Kairos Future, 2017). Many scandals over the years have led to food safety issues, disease outbreaks and misrepresentation of products. The sharing of information and tracking and tracing of products across the supply has been a longstanding issue and is key to creating transparent supply chain ecosystems.

There are many solutions that have aimed at addressing this issue. Existing paper-based and mostly manual methods are slow, repetitive, inefficient and error-prone with up to 70% of data being replicated (Accenture, 2018; Kshetri, 2018). Advancements in technologies such as RFID and cloud computing have led to many IoT approaches to provide data on products as they move across the supply chain in order to track them and verify their origin. These solutions however have been met with limited success. Common issues are: tracking information is not validated, it is difficult to provide continuity of information across multiple parties and information is mostly still managed by each stakeholder thus requiring high levels of trust (Xu, et al., 2017; Shanley, 2017).

The current realities of tracking and tracing in the supply chain are the many challenges relating to data exchange between parties, the creation of trust and the challenges in insuring the immutability of product data and transactions (Shanley, 2017). This means that there is often areas of restricted visibility in the supply chain.

The industries' attention has turned towards blockchain, as it's a technology that can potentially increase visibility across the supply chain. This is mainly due to its ability to provide an immutable digital ledger of a products history throughout its supply chain journey. Organizations in general struggle to capitalize on new technologies due to a lack of know-how. In the case of blockchain, which is both a very new technology and at the same time quite complicated, this is especially true (Denner, et al., 2018). Industries, including supply chain, have struggled to adopt blockchain due to general lack of understanding and lack of research knowledge on where and how to apply it.

A systematic review on the current state of blockchain research has revealed that academic research on the technology has been limited, with the first research publications only appearing in 2013 and interest only catching on in 2015 (Yli-Huumo, et al., 2016). Since then, research has predominantly centered around the technical side of blockchain, focusing on aspects such as cryptocurrencies, its design, features and other technical matters (Risius & Spohrer, 2017; Yli-Huumo, et al., 2016; Nofer, et al., 2017; Gausdal, et al., 2018). Most papers are also conceptual and do not focus on its possible applications and real world applicableness. As an illustration of blockchain's relative 'newness', Fig 1-1 below showcases the number of documents that appear under the search terms '*blockchain*', '*blockchain + supply chain'*, and *'blockchain + supply chain + tracking and tracing'* from the online e-database Scopus. It is clearly evident that research into this field is fairly recent, especially in the case of supply chain and tracking and tracing. Research documents containing the terms 'blockchain' along with 'supply chain' have only begun appearing after 2015. Also, the pie chart bottom left shows that most research is focused on the fields of computer science (Scopus, 2019).

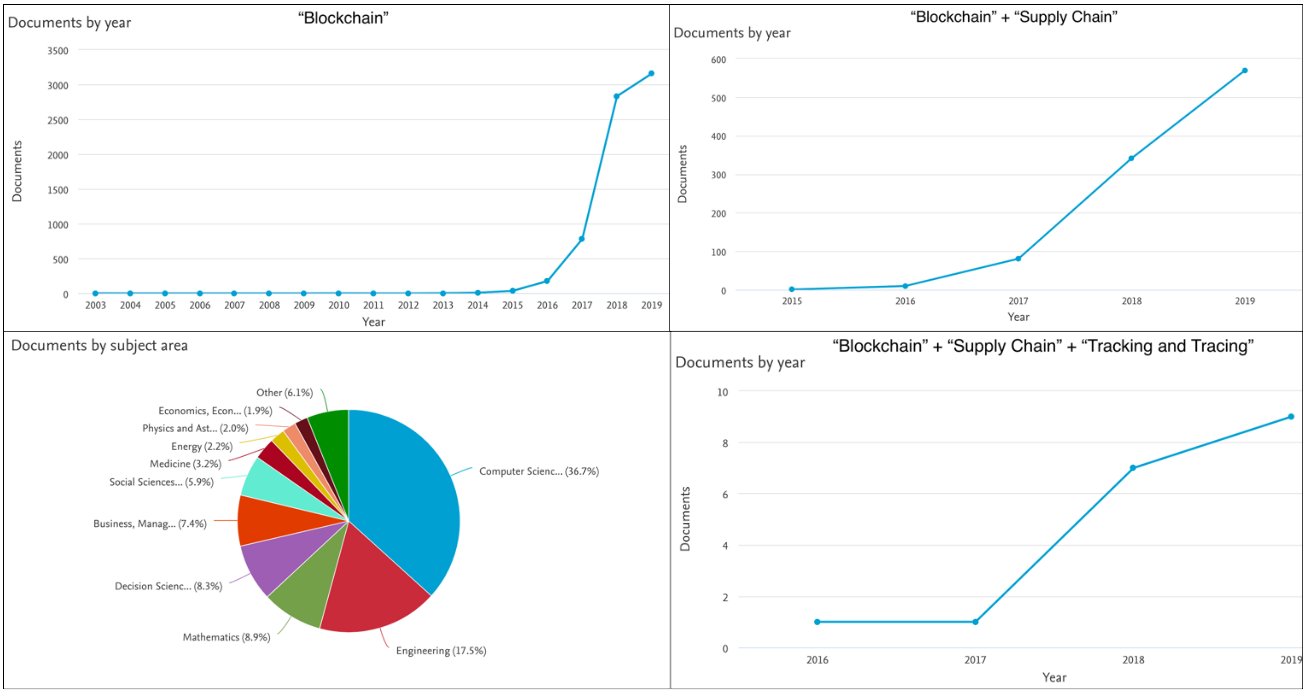


Figure 1-1 Popularity and Scope of Blockchain Research

One of the barriers to entry that is preventing blockchain from gaining traction in supply chain tracking and tracing, has been the lack of knowledge surrounding its use and development. For example, there is almost no literature that investigates existing platforms and their suitability for developing applications in industry (Macdonald, et al., 2017). There is thus a strong need for tools such as models, frameworks or reference architectures that can guide supply chain actors in the design, development and deployment of blockchain technology (Wang, et al., 2016; Scriber, 2018). Blockchain needs to make sense for investors, executives and technologists in order for the technology to progress. This drives the need for the development of a generic business approach that can clarify the various aspects and decisions whilst providing guidelines for its use in supply chains.

To date there have been some frameworks that address the application of blockchain in the supply chain, however they have their limitations. Most of the frameworks only deal with certain specific aspects (such as implementation) and are not as detailed and comprehensive as reference architectures. Reference architectures cover more aspects and show their interrelation. Research also supports that reference architectures are more suited to the design and re-design of information systems (Du Preez, et al., 2015). Reference architectures have been used to support and guide the use of other digital technologies in the supply chain such as IoT (Verdouw, et al., 2018). There is, however, no reference architectures in literature that support the design and implementation of blockchain in the supply chain.

1.2.2 Problem summary

Figure 1-2 presents a summary of the findings from the problem background section above. Along with this, an overall summary of the problem is presented.

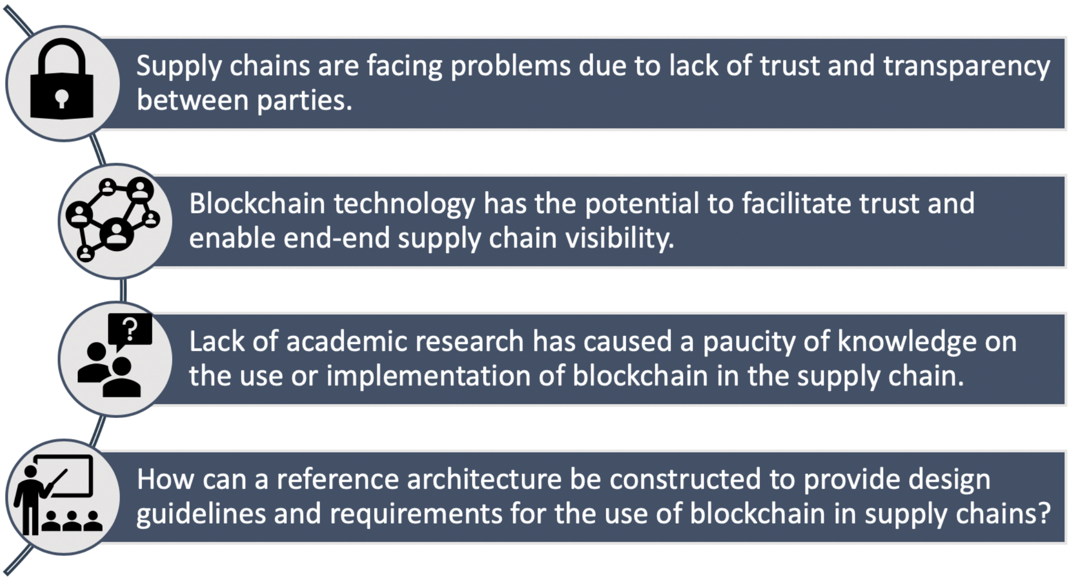


Figure 1-2 Problem summary

Today's supply chains are facing problems due to a lack of transparency and visibility between different parties. This is caused by problems with regards to tracking and tracing where information is held up in silos. Current methods of tracking and tracing are slow, fragmented and inefficient. Changing consumer behaviour, changes in the market and new technology trends are demanding that supply chains become more transparent with regards to information sharing. Key abilities such as the verification of product characteristics and product provenance is required. Blockchain technology has been identified as one of the technologies that can enhance end-to-end visibility and have been included in the digitalization strategy of many supply chain companies.

However, the technology, invented in 2008, is nascent and complicated in nature. The general lack of understanding around blockchain has stifled adoption and in turn has led to limited real world successful implementations. Further, academic research on blockchain has been limited. Research has focused more on its technical nature and relation to cryptocurrencies as opposed to research into developing industry applications.

The need for a tool, model or architecture that can help supply chain professionals understand the suitability, design and deployment of blockchain technology has been stressed across academia and industry. There is currently no collection of knowledge surrounding the use of blockchain in supply chains. No models, frameworks or architectures have been identified that highlight the various aspects of the technology that need to be taken into consideration. Thus, the questions are: *'what are the various requirements for the design of blockchain track and trace solutions in the supply chain'* and *'how can a reference architecture be constructed to support the design of blockchain track and trace systems'?*

The main research objective is to construct a Design Reference Architecture (DRA) that contains generic design guidelines, principles, best practices and requirements that can be used to help guide and support supply chain professionals in the design of blockchain track and trace solutions. It hopes to bring together the current knowledge into a single architecture that can be easily consulted to help guide the design process.

1.3 Research questions

In order to approach this thesis topic, various aspects surrounding the problem statement need to be investigated and understood. These aspects involve, amongst others, an in depth study of blockchain technology, including its use in tracking and tracing and how it addresses problems in the digital supply chain. To answer the main question, eight sub questions were designed so that when answered, they would help support the main research question. Table 1-1 below, describes these sub-research questions.

Table 1-1 Research Questions

Research Questions		
Main question		How can a generic Design Reference Architecture be constructed to help guide teams in developing blockchain track and trace applications in the supply chain?
Sub questions	1	What is blockchain technology and what are its main application benefits in the supply chain?
	2	What are the latest technological architectures of blockchain technology?
	3	What are the latest challenges in supply chain digitalization and tracking and tracing?
	4	How can blockchain technology enable tracking and tracing in the supply chain?
	5	What use cases exist for blockchain in the supply chain, specifically related to tracking and tracing?
	6	What are the various blockchain design requirements, key principles, guidelines, and considerations needed for the design of blockchain supply chain systems?
	7	How can a reference architecture be designed to support the development of blockchain in the supply chain?
	8	Would such a reference architecture provide sufficient guidelines for design teams to develop blockchain based tracking and tracing solutions in the supply chain?

1.4 Research objectives

By answering each of the above questions, the objective of the study is to construct a design reference architecture that contains the various guidelines, principles, best practices and decisions that companies have to consider when designing blockchain technology systems in supply chain tracking and tracing. The overall objective will be supported by various sub objectives that aim at addressing current problems and research gaps identified. These sub objectives are shown in table 1-2.

Table 1-2 Research Objectives

Research Objectives	
Main Objective	Construct a design reference architecture to help guide teams in developing blockchain track and trace applications in the supply chain.

Sub objectives	1	Investigate blockchain technology, how it works and what its main benefits in the supply chain are.
	2	Identify, describe and compare the latest blockchain architectures.
	3	Identify the current challenges in supply chain tracking and tracing.
	4	Illustrate how blockchain can better enable tracking & tracing in the supply chain.
	5	Describe and analyse the current blockchain supply chain use cases in existence.
	6	Identify the important design requirements and considerations for the use of blockchain in supply chain track and trace.
	7	Construct a reference architecture that can guide teams in developing blockchain track and trace solutions for the supply chain.
	8	Test the validity and applicableness of the architecture with a practical case study in industry and expert analysis.

1.5 Research design

The research design provides a framework for collection and analysis of data. It can be seen as the philosophical approach or strategy that will be applied throughout the project in order to satisfy the research question posed (Saunders & Tosey, 2013). A research philosophy refers to the belief one subscribes to when collecting, analysing and presenting data. The four major philosophies of western science is positivism, realism, interpretivism and pragmatism. Since no experiments or real life implementations will be done, the research project leans more to the side of pragmatism where the goal would be to explore certain concepts, learn from case studies and then form a conclusion. This conclusion would serve to add practical knowledge, meaning and value. A pragmatic research philosophy can employ any combination of research methods needed in order to obtain answers to the questions. This is key to a study in a new research area, such a blockchain, where there are few 'footsteps' to follow. The researcher has to forge his own path in order to achieve the project goal.

As little formal research exists in this field, the author will start by formulating a research question followed by making observations, finding patterns, creating a hypothesis, analysing and validating that hypothesis and finally forming a theory. This is distinctive of an inductive research approach, opposed to deductive where a specific hypothesis is tested based on experimental results. True to the pragmatic philosophy of this study, a combination of strategies surrounding data collection will be used. Existing literature on blockchain, case study analysis as well as semi structured interviews will be used in collection and validation of data in this project. This is typical of a mixed method approach in which the use of qualitative and quantitative data helps offset the limitations of each individual method.

This project will aim to present a specific snapshot in time regarding the use of blockchain in the supply chain. It can thus be characterized as having a cross sectional time horizon, where the current state is being observed instead of the change in state over a time period. A comprehensive literature review will be used to help form a background understanding of the topic, as well as to extract observations in order to form a hypothesis. In this case, the blockchain design requirements will be extracted in order to construct a design reference architecture. A case study and semi structured interviews will be used to validate the hypothesis. In this way, the applicableness, practicality and validity of the architectures content can be tested. The research methods employed by this project can be summarized against the research questions and objectives. Table 1-3 provides the research methodology summary.

Table 1-3 Research Methodology

		Research Questions	Research Objectives	Research Methodology
Main question		How can a Design Reference Architecture be constructed to help guide teams in developing blockchain track and trace applications in the supply chain?	Construct a design reference architecture to help guide teams in developing blockchain track and trace solutions in the supply chain.	Mixed methods approach.
Sub questions	1	What is blockchain technology and what are its main application benefits in the supply chain?	Investigate blockchain technology, how it works and what its main benefits in the supply chain are.	Structured literature review analysis.
	2	What are the latest technological architectures of blockchain technology?	Identify, describe and compare the latest blockchain architectures.	
	3	What are the latest challenges in supply chain digitalization and tracking and tracing?	Identify the current challenges in supply chain tracking and tracing.	
	4	How can blockchain technology enable tracking and tracing in the supply chain?	Illustrate how blockchain can better enable tracking & tracing in the supply chain.	
	5	What use cases exist for blockchain in the supply chain, specifically related to tracking and tracing?	Describe and analyse the current blockchain supply chain use cases in existence.	
	6	What are the various blockchain design requirements, key principles, guidelines, & considerations needed for the design of blockchain supply chain systems?	Identify the important design requirements and considerations for the use of blockchain in supply chain track and trace.	Structured literature analysis, evidence from existing case studies.
	7	How can a reference architecture be designed to support the development of blockchain track and trace in the supply chain?	Construct a reference architecture that guides teams in developing blockchain track & trace solutions for the supply chain.	
	8	Would such a reference architecture provide sufficient guidelines for design teams to develop blockchain based tracking and tracing solutions in the supply chain?	Test the validity and applicableness of the architecture with a practical case study in industry and expert analysis.	Practical case-study analysis semi structured interviews with industry experts.

1.6 Research process

The main task of this research is to develop a design reference architecture containing design guidelines, requirements and considerations that will help guide companies to design blockchain track and trace solutions for the supply chain. Figure 1-3 illustrates the research process used to approach this task. A literature review will first be done where blockchain will be examined, its technological architectures analysed and its role in supply chain tracking and tracing clarified. Following this, the important design requirements need to be defined. By examining the relevant blockchain requirement frameworks, consulting known use cases and knowledge from the literature study, the important blockchain design guidelines are extracted. These requirements are then clarified and used to design the reference architecture.

The next phase is to validate the reference architecture. An industry case study will be set up with a partnering company. The case study will involve a real life blockchain track and trace application to a supply chain. The case study will be used to obtain a clearer insight into blockchain track and trace and serve as a way to demonstrate the practicality and validity of the reference architecture. Semi-structured interviews with industry experts will also be done in order to provide a further analysis of the reference architecture's validity and applicability. Finally, the results will be detailed and a conclusion provided along with further research.

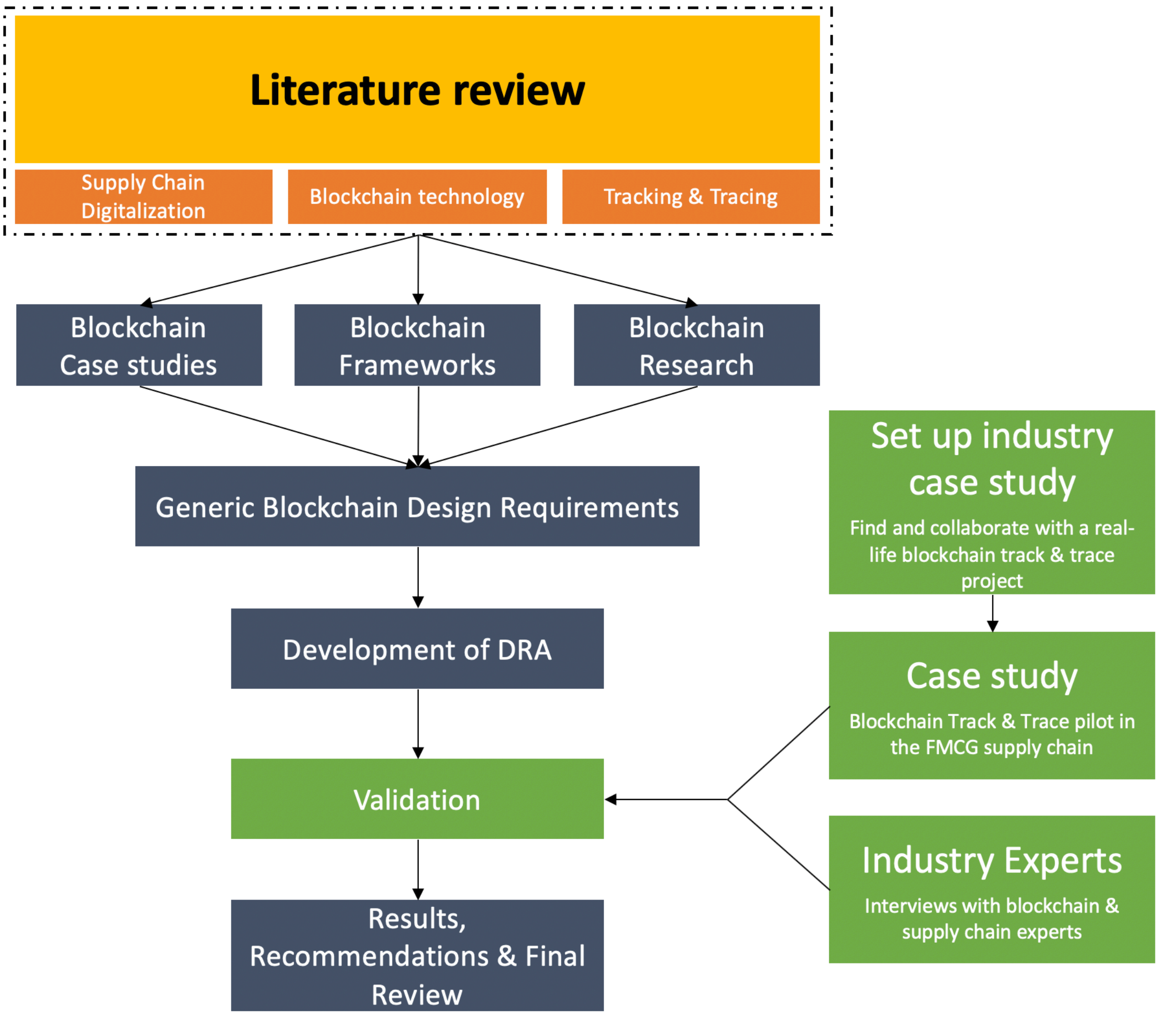


Figure 1-3 Research Process

1.7 Delimitations and limitations

In exploring new areas of research it is important to state delimitations and disclose the limitations. The previous sections outlined the theoretical position of the thesis, the design of a reference architecture for the use of blockchain technology in the supply chain. In this section the delimitations, which are the explicit boundaries for the study, are set, and the limitations or conditions outside of the researchers control are stated.

Blockchain technology is complex, has many facets and is rapidly becoming a very broad field of research. It was thus decided to narrow the scope down to areas of research that are important to the study objectives. Casting the net too wide would result in unnecessary complexities and information that would not suite the overall objective. This can potentially be of negative effect to the study. The sections below include some of the arguments for study delimitations followed by a summary.

1.7.1 Levels of complexity

At its core, blockchain involves complex cryptographic algorithms and mathematics. This makes the technology often a challenging task to explain and is one of the reasons why adoption is hindered. Blockchain can be examined in a variety of different levels of complexity and studies often use levels that are unnecessarily complex, leading to the main message being obscured. Thus, in this study, only the level of complexity needed will be explained. An in depth discussion of the mathematics, computing and inner workings of the cryptographic algorithms is mostly outside of the scope of this study unless needed for a particular illustration.

1.7.2 Excluding other DLT technologies

Cryptographic advancements in the last 10 years, as a result of blockchain, has led to developments of many other similar distributed ledgers technologies. Distributed ledgers technologies or DLT's also consists of a ledger file stored on many different nodes in a network not controlled by a central authority. Blockchain is characterized as a type of distributed ledger, however it is different because it has a 'block and chain' type structure. This is what sets it apart from other DLT technologies. Blockchain is a distributed ledger, but not every distributed ledger is a blockchain. Although both DLT technologies and blockchain offer conceptual breakthroughs in managing information, this study will specifically focus on blockchain only. Other DLT technologies will not be considered as that would be an entirely different study and one that could be taken up in future. Blockchain is the most well-known DLT and currently in the focus of academia and industry.

1.7.3 Focus on supply chain and track & trace

Besides finance, blockchain has the potential to bring advances across many different industries and use cases. The focus of this study will be limited to supply chain, more specifically tracking and tracing within the supply chain. In the problem statement it was clarified that there is a need for research directed at specific use cases. Blockchain has many other potential uses in the supply chain such as microfinancing suppliers using smart contracts or for facilitating IoT system security. Many of the other uses are still experimental and theoretical. Tracking and tracing is currently the main focus area of research for blockchain in the supply chain. Blockchain tracking and tracing is being tested in automotive, food and pharmaceutical supply chains.

A further delimitation is to focus the case studies and blockchain requirements mostly towards food supply chain tracking and tracing. The reason for this is because the use of blockchain in food supply chains is currently the main focus of the industry as its seen as the area where the most value exists (Kshetri, 2018). By narrowing the scope to this area, clearer and more achievable objectives can be formulated to target specific problems and literature gaps. Although this focus will be made, the overall architecture will however strive to provide generic principles that will be applicable to other supply chains outside of food applications.

1.7.4 Excluding practical implementation or working prototype

The project will strive to construct a design reference architecture of important blockchain requirements and guidelines, tested using a case study. Actual implementation guidelines or design of a working prototype are not in the scope of this study. At this early point in blockchain research, it is initially important to identify the various design considerations and guidelines before research on its actual implementation can commence. This study will however strive to serve as a basis for future implementation and prototypes.

1.7.5 Excluding cryptocurrencies and tokenization aspects

Blockchain is the underlying technology of cryptocurrencies and thus one of the many uses of blockchain. In this study, the use of blockchain is being directed towards supply chain for visibility and transparency. The specific application of blockchain to facilitate financial payments will not be covered as it is outside of this projects scope. Asset tokenization is another blockchain benefit that might have an impact in future but was not a factor in supply chain track and trace at this point. Therefore these topics would be excluded from this study.

1.7.6 Summary diagram

In summary, this study will only focus on blockchain technology and exclude other DLT type platforms and cases, with the scope highlighted in figure 1-4.

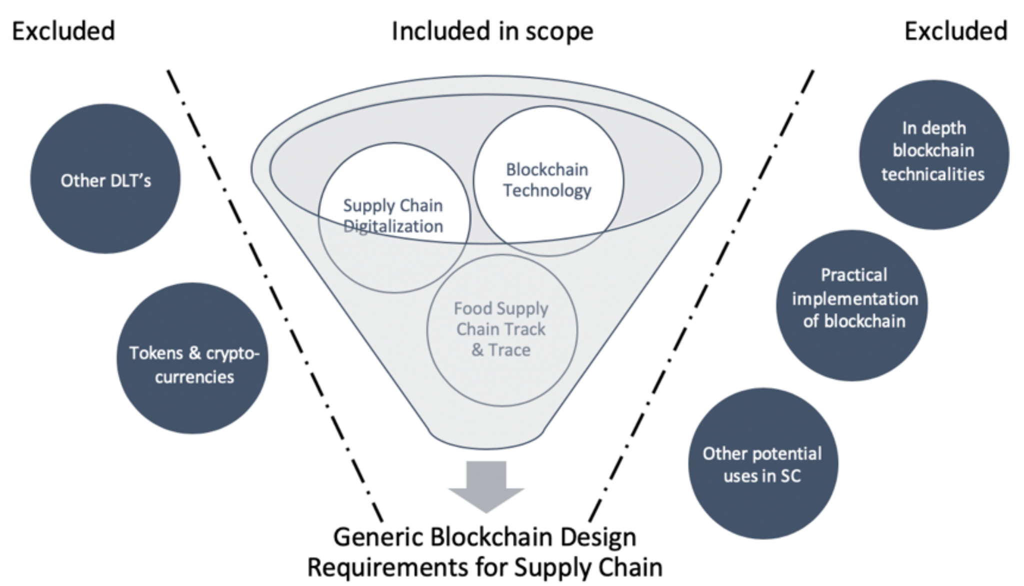


Figure 1-4 Project Scope

It will exclude technical aspects of blockchain such as cryptographic algorithms that are not relevant to the topic as well as other aspects of the technology such as tokenization and cryptocurrencies. Its focus will mainly be on the tracking and tracing of products in the food supply chain, as this is currently the best identified use case for blockchain and the area in which there is the most interest and development. Regardless of this, the principles, guidelines and results generated, will strive to remain generic to suit many other uses of blockchain in the supply chain. The diagram 1-4 illustrates this point.

1.8 Ethical considerations

In the undertaking of this masters project, it is important to consider and clarify all ethical issues that may arise. Possible ethical issues may arise during the data collection and validation phases. As described, the project will be validated through a practical case study along with feedback from industry experts gathered by means of structured interviews. Ethical clearance for this project was granted and it was classified as low risk. For a more in depth discussion on the consideration of ethical issues, the appendix can be consulted. When collecting such data, the following issues will be considered:

Table 1-4 Ethical Considerations

Relevant ethical considerations	
Informed Consent	The participants of an interview or evaluation would be fully informed and made clear of its purpose and use. This is made clear so that the participant may make an informed decision to participate in sharing the information requested.
Voluntary participation	Participants take part in the study voluntarily and have the right to withdraw at any time without negatively impacting the outcomes of the study.
Confidentiality	Any identifying information regarding participants will not be made available or accessible to anyone but the study co-ordinator.
Anonymity	Anonymity is a stricter form of confidentiality with the identity of the participant not known to the research team. This is difficult to apply as participants are usually known to those undertaking the research but will be applied if needed.
Assessment relevance	When collecting information, only the relevant components will be assessed. Evaluations will be kept simple and to the point of intention.

1.9 Thesis outline

Figure 1-5 presents a summary of the thesis outline. In the first chapter, the problem statement will be presented along with the overall project description. Chapter two will present the literature study. It will start with a background on supply chain digitalization, tracking and tracing and its role in dealing with current challenges such as supply chain visibility. An in depth examination on blockchain technology will be done covering factors such as its latest technological architectures, benefits for supply chain, existing case studies and significance in supply chain digitalization.

Chapter three will cover the topic of reference architectures. A short background will first be given on reference architectures followed by a methodology for designing a reference architecture that can aid in the application of blockchain technology. The various blockchain application requirements will be extracted from identified sources for use in the design reference architecture. Chapter four will cover the design reference architecture for the application of blockchain technology in the supply chain. It will give an overview of the overall architecture followed by a detailed discussion on each section.

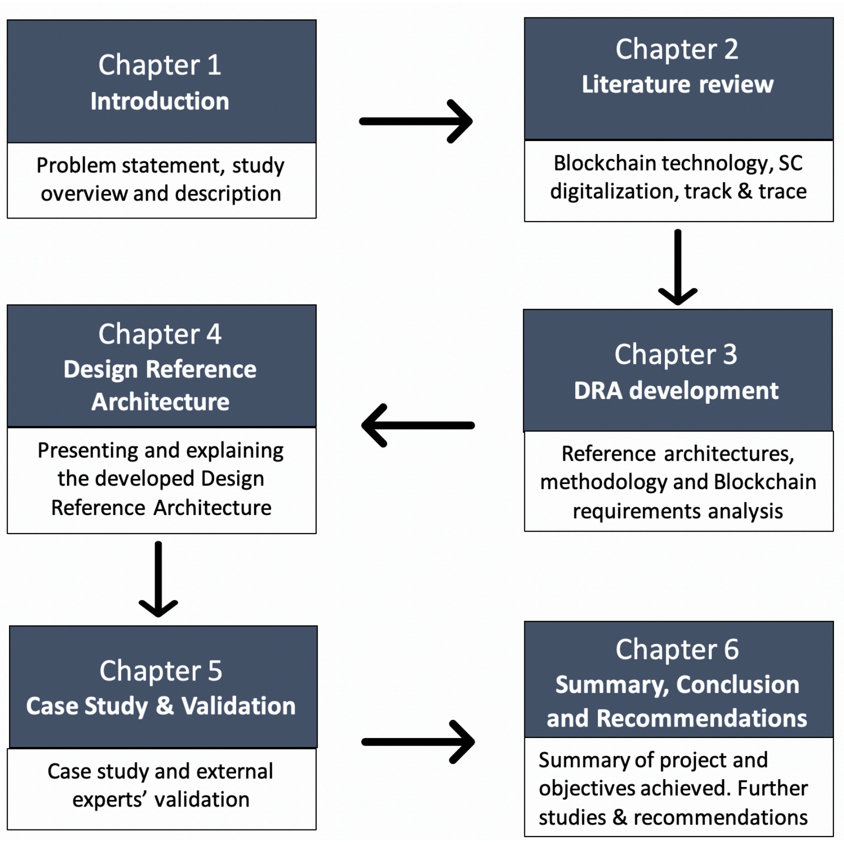


Figure 1-6 Thesis Outline

Chapter five will comprise of the validation for the design reference architecture which will take place in two parts. The first part will involve an application of the architecture to a supply chain tracking and tracing case study. This will aim to test the practicality of the architecture as well as develop a better understanding of tracking and tracing using blockchain in real life. The second part of the validation will involve interviews with industry experts that will focus on the validity of the design reference architecture itself. In chapter six, a summary of the research done will be presented, followed by a conclusion and recommendations for further research.

1.10 Thesis comments

In this section, a few further comments will be given regarding the study.

1.10.1 Tools used

In order to analyse the vast number of papers, journals, articles, case studies, reports, websites and other sources of information on blockchain technology in the supply chain, the qualitative data analysis software Atlas.ti, was used. Atlas.ti is the world's leading software for qualitative and mixed methods data analysis. It has a powerful set of tools that allows users to manage data effectively and efficiently. It was found particularly useful for identifying the main sources and extracting important information from them such as the design requirements. The ability to code different papers in order to show their interrelation on similar topics, helped to attain a more in depth understanding of the current blockchain developments in the supply chain.

Research Gap	16	0	0	Nicholas Louw	10 Sep 2018
Q1 - Latest tech Architectures	17	0	0	Nicholas Louw	10 Sep 2018
Q3: Use Cases in SC	17	0	0	Nicholas Louw	10 Sep 2018
Blockchain Suitability	19	0	0	Nicholas Louw	11 Sep 2018
Blockchain Definition	21	0	0	Nicholas Louw	10 Sep 2018
supply chain	22	0	0	Nicholas Louw	14 Oct 2018
Blockchain Risks/disadvantages	24	0	0	Nicholas Louw	10 Sep 2018
SC digitalization	24	0	0	Nicholas Louw	18 Mar 2019
public vs private	25	0	0	Nicholas Louw	02 Oct 2018
Q2: Key factors (Implementation and A...	28	0	0	Nicholas Louw	10 Sep 2018
Q10: Frameworks/decision models	28	0	0	Nicholas Louw	10 Sep 2018
Blockchain Advantages	32	0	0	Nicholas Louw	10 Sep 2018
Blockchain design considerations	34	0	0	Nicholas Louw	10 Sep 2018
Consensus Mechanisms	46	0	0	Nicholas Louw	10 Sep 2018
Problem statement	61	0	0	Nicholas Louw	02 Oct 2018

Result: 109 of 109 Code(s)

Figure 1-7 Screenshot of Atlas.ti's coding function

1.10.2 Courses and Conferences

At the commencement of this masters project, the author completed an IBM Blockchain Foundation for Developers course in order to gain a better insight into the technology. The author also attended a Blockchain Supply Chain Innovation conference in Frankfurt, Germany, where some of the latest advances, use cases and developments were presented. Some of these developments were helpful and was incorporated into the study.

1.10.3 Partnering Company

Developing a relationship with a large international supply chain company, helped transfer learnings from the real world into the development of the reference architecture. It also provided a basis for validation. The company was approached as they were in the process of developing a blockchain pilot program and the relationship between the author and the company would be mutually beneficial in furthering the development of blockchain in the supply chain.

Chapter 2
Literature Review

This chapter is devoted to a review of topics in the literature that are relevant to the problem briefly described in the previous chapter. As shown in figure 2-1, the chapter will start with an overview of supply chain digitalization and how tracking and tracing plays an important part in enabling supply chain ecosystems. Following this, an overview of tracking and tracing will be given including the advantages that blockchain presents for this mechanism of supply chain visibility. The next subchapters will be dedicated to blockchain technology, its advantages for the supply chain, existing case studies and latest technological architectures. After this, a summary of the literature review will be given. An overview is provided below.

The overall goal of the literature review is to evaluate the current state of blockchain technology in the supply chain based on the latest academic sources and findings from industry. It will strive to create a body of knowledge on which the rest of the project can be based.

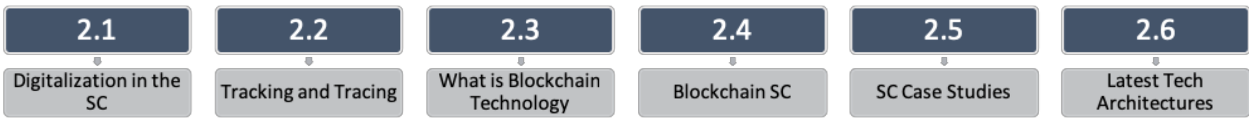


Figure 2-1 Chapter 2 overview

2.1 Digitalization in the supply chain

2.1.1 Overview

New technologies and changing consumer habits are disrupting consumer oriented businesses and supply chains in a fundamental manner. High internet penetration, ubiquitous availability to information and rapid growing social networks are affecting consumer buying habits (Capgemini, 2011). The 2019 Global Consumer Insights Survey explains that consumers are becoming ever more digital and conscious of the environmental and health implications of their actions and purchases (PWC, 2019). These new habits are pressuring supply chains to become more transparent and agile. New initiatives such as digitalization and Industrie 4.0, and technologies including IoT, AI, Blockchain, Big Data and Cloud computing are creating disruptions to existing systems but at the same time provide new opportunities to those who adopt them. Today's supply chains are not equipped to thrive in this new environment and needs to be transformed address current problems and meet the demands of the future (Schrauf & Berttram, 2016; Capgemini, 2011).

Digitalization can be defined as the adoption of new technologies to improve or disrupt existing business models (Denner, et al., 2018). The digitalization of supply chains involves the adoption of new technologies and systems to transform the existing rigid supply chain structures into more open, flexible, agile and collaborative digital ecosystems that are able to compete and thrive in the digital age of tomorrow.

2.1.2 Traditional vs Digital Supply Chains: The Silo vs Ecosystem model

Supply chains today are already using a host of different digital technologies such as ERP systems, cloud technology, sensors, logistics and planning systems, forecasting models and many more for increased efficiency and effectiveness. The question is thus, '*why is there a need for digitalization and how is it different to the current model of digital technologies used in the supply chain*'?

The current traditional supply chain, which is also referred to as a hybrid supply chain, rely on a mix of electronic IT supported processes and paper-based processes and documentation. The different companies, suppliers, manufacturers and distributers in the supply chain make use of a mixture of digital systems and manual paper-based processes to complete required supply chain tasks. The organizational structure of current supply chains are characterized by functional and geographically separate silos (Capgemini, 2011; Schrauf & Berttram, 2016). These silos represent the fact that companies' technology systems are dis-separate and isolated from one another with little information sharing taking place between them. Products and materials move between these discrete and vertically integrated IT systems from start to end. This model has resulted in very rigid structures, inaccessible data, organizational flexibility and poor collaboration, which leads to sub-optimal performance. Lack of transparency means that it is ill optimized to remain competitive in a world where supply chains need to be more agile and transparent. Divergent information processes create inconsistent/redundant data and result in several inefficiencies. In the changing world of business, it is no longer company vs company competition but supply chain vs supply chain (SAP, 2018). The integration of all nodes of the supply chain is fundamental to achieving a competitive advantage (Palamara, 2018). Silo based traditional supply chains pose a threat to competitiveness in an increasingly digital world. Below is a summary of some of the limitations of traditional supply chains (Capgemini, 2011; Zhang, 2019).

Table 2-1 Limitations of Traditional SC's

Key Limitations of Traditional Supply Chains	
- Overly complex IT landscapes	- Sub-optimal use of locations
- Lack of end-to-end process integration	- Sub-optimal use of labour cost differences
- Lack of transparency	- Sub-optimal bundling of tasks
- Lack of agility	- Lack of traceability
- Outdated data sharing methods	- Compliance challenges

Digital supply chains on the other hand are characterized as ecosystems instead of silos. They are more open, have extensive information sharing capabilities, provide automation and enable superior collaboration and communication across digital platforms resulting in improved agility, reliability and effectiveness (Capgemini, 2011; Schrauf & Berttram, 2016). The goal of digitalization is to break down the '*silo*' structure of traditional supply chains and construct an ecosystem where information and technology capabilities between different actors are shared rather than separated. Ubiquitous availability of information is at the centre of the digital supply chain. The process of transforming a supply chain from traditional to digital will involve not only the identification of the correct technologies, but also using the right people with the right skills and capabilities to drive this change. As many of the technologies involved with digitalization is already in existence, to the role of organizational structure and change management plays a major role in supply chain digitalization. Table 2-2 below provides an overview of the differences between traditional and digital supply chains (Schrauf & Berttram, 2016). From this it becomes clear what the advantages of the digital supply chain are and why it will revolutionise current processes. The next section examines, in more detail, the different elements that are expected to drive this revolution.

Table 2-2 Traditional vs Digital SC

	Traditional Linear SC (hybrid/silo)	Digital SC Ecosystem
Transparency	Limited view of supply chain	Complete view of supply chain
Communication	Information delayed as it moves through each organization	Information available to all supply chain members simultaneously
Collaboration	Limited visibility to the entire chain, hindering meaningful collaboration	Natural development of collaboration depth to capture intrinsic supply chain value
Flexibility	End customer demand distorted as information flows along the material path	End customer demand changes are rapidly assessed
Responsiveness	Different planning cycles resulting in delays and unsynchronized responses across multiple tiers	Real-time response on planning and execution level (across all tiers to demand changes)

Figure 2-2 showcases a visual representation between traditional and digital supply chains (Deloitte, 2019). In the traditional hybrid supply chain, information travels step by step in a sequential manner between different supply chain partners. If one partner requires information from another further up or down the chain, they have to acquire it in a linear fashion, leading to delayed action. In the digital supply chain, this limitation is overcome as there is real time data sharing between all partners in the network. This leads to greater reaction times and transparency which improves supply chain agility.

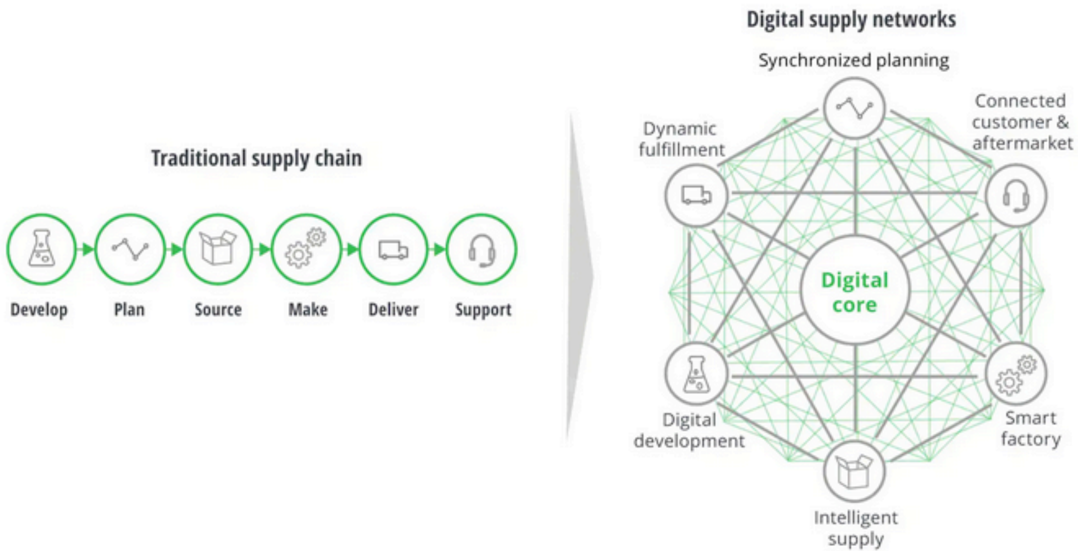


Figure 2-2 Traditional vs Digital SC

2.1.3 Elements of Supply Chain Digitalization

In a recent literature analysis, four elements of digitalization related to supply chain management were identified: big data analytics, Industrie 4.0, additive manufacturing and advanced tracking technologies (Ivanov, et al., 2019). These elements, shown in figure 2-3 are further described below.

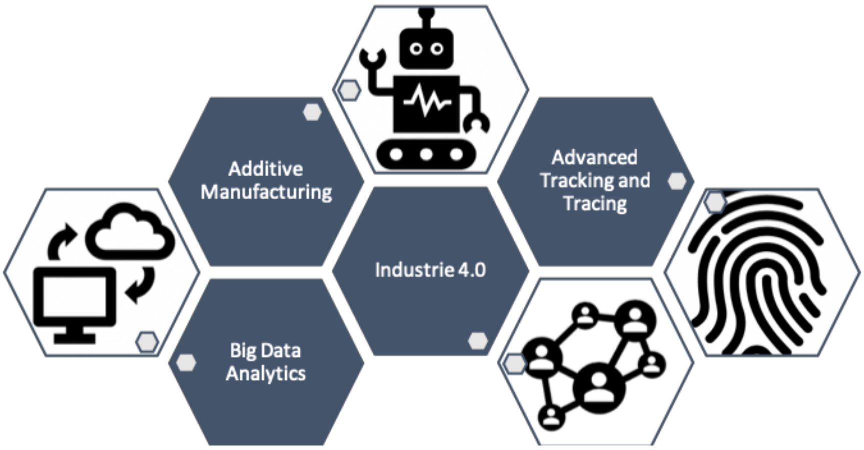


Figure 2-3 Elements of SC digitalization

Big data

Big data is based on the extraction of knowledge from a large or vast amount of data to help facilitate data-driven decision making. Big data has been one of the most focused digital technologies in the SCM industry. Big data analytics can be found in applications from all parts of the supply chain including procurement processes, manufacturing shop floors, routing optimization, safety management, operation monitoring and many more. Big data is predicted to become part of many other supply chain processes in the near future. An example in industry is a Mercedes Benz plant producing cylinder heads (in Untertürkheim, Germany), that uses predictive analytics to analyse over 600 different parameters influencing the quality of piston heads.

Industrie 4.0

Industrie 4.0 refers to the fourth industrial revolution which involves a new wave of smart manufacturing and networking where machines and products interact with each other without human control. It is a German term but it is also often referred to as smart manufacturing or smart factory in literature. It is an umbrella term for a collection of new technologies that enable new production strategies, with the use of cyber-physical-system principles, based on highly customised assembly systems with flexible manufacturing process design. Simply put, it involves factories and machines that are wirelessly interconnected to communicate with each other and are able to make their own decisions. This process decentralises control and decision making thus increasing efficiency, agility and optimization. An example in industry is from Amazon who is developing a self-learning robot including and automatic packaging system. The robot will be able to pick-up items ordered and package them appropriately, while secure data provides the opportunity to save the ideal packaging strategy of a product.

Additive manufacturing

Also known as 3D printing, additive manufacturing is the process of joining materials layer upon layer as opposed to subtractive methods such as machining. It requires software (to design a 3D item), hardware (to print the item) and materials (used to form the item) to produce a 3D printed part (AutoDesk, 2019). It is generally used for rapid prototyping as parts can be designed and printed much faster than by using conventional manufacturing methods. This allows companies to experiment with new business models which is crucial for innovation (Nowiński & Kozma, 2017).

There are a range of applications for 3D printing in the supply chain, from producing spare parts to making highly customized items. Additive manufacturing can increase manufacturing flexibility, achieve shorter lead times, increase product individualization and reduce inventory (Ivanov, et al., 2019). An example of rapid prototyping applied in industry is the Adidas Speed-Factory (in Ansbach, Germany) where they have introduced innovative 3D printing technology to the production process. In the Speed-Factory, Adidas is able to produce limited addition and highly customized shoes to meet in demand trends instantly. The factory is almost completely automatic and can produce short production runs of in demand shoes at short lead times. The Speed-Factory has allowed Adidas to automate processes, produce faster than before, move their production closer to the market, meet customer demands more rapidly, hold less inventory and make personalized models for customers.

Advanced tracking and tracing technologies

To make decisions in dynamic and uncertain environments such as in supply chains, real time information acquiring and sharing is of crucial importance. Track and trace systems aim to identify deviations and provide alerts when disruptions have occurred, providing actions to help control supply chain operability. By using technologies such as mobile devices and RFID, system feedback can be provided and effectively communicated throughout the supply chain. In recent years, blockchain technology has been pinned as a key enabler to tracking and tracing solutions in the supply chain. The main idea of this is to increase visibility and transparency between supply chain actors and to aid in record keeping. An example of this is with IBM and Wal-Mart who have deployed a blockchain based track and trace system to increase food safety control using blockchain technology.

2.1.4 The role of tracking and tracing using blockchain in supply chain digitalization

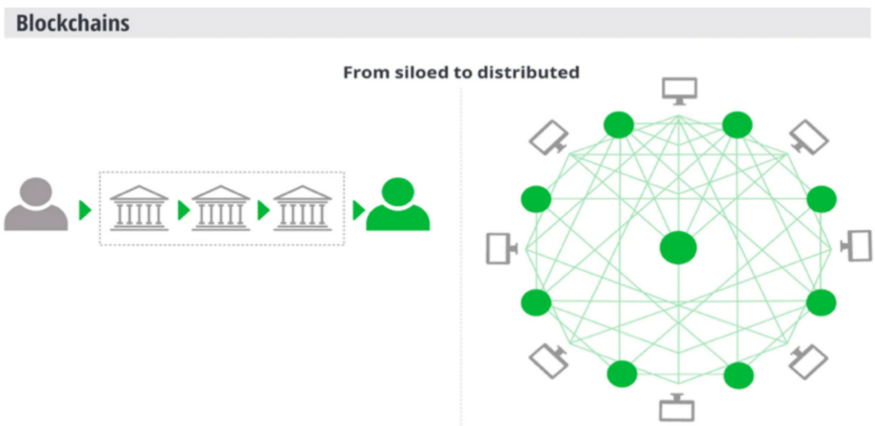
Tracking and tracing has been identified as one of the mechanisms of horizontal information sharing in supply chain digitalization. The use of tracking and tracing, specifically using blockchain technology, to break down silos of information in the supply chain has been widely supported across research. Table 2-3 summarizes some research findings on this topic.

Table 2-3 Statements on Blockchain track & trace

Statement	Author(s)
Blockchain will break down the silos of information and make processes faster and cheaper.	(Lo, et al., 2017)
Tracking and tracing using blockchain can help eliminate organizational silos that exist in the supply chain and make the supply chain more efficient across different levels. Using blockchain for tracking and tracing will provide better information of products across the supply chain.	(Sadouskaya, 2017).

Statement	Author(s)
Blockchain can liberate data that was previously tied up in silos. The impact of this would mean higher levels of transparency across the supply chain empowering consumers to make better choices about the products they buy amongst many other benefits.	(Heutger, et al., 2018)
Breaking down organisational silos and regrouping them around value-creating processes will help reduce organizational complexity and further aid in enhancing supply chain agility and cross functional working.	(Christopher, 2000)
One of the current challenges in supply chains is limited visibility and data capture as a result of siloes which limits information sharing. This results in incompatibilities in data and blind spots with regards to tracking and tracing goods. Blockchain' can address this issue.	(Chamber of Digital Commerce, 2016)
Blockchain enables the multiple parties to access the same data addressing the issues of siloed databases that are not visible outside of a single organization.	(Goldman Sachs, 2016)
Factories are generally organized into silos. In Industrie 4.0 it will be vital to combine data, integrate systems and processes and make decisions based on cross functional information.	(McKinsey & Company, 2015)
Enterprises will have to collaborate across organizational silos and blockchain can be used in order to unlock greater economic value in this manner.	(Galves, et al., 2018)
Using blockchain to establish trust and validity in data improves the ability to share data across silos whilst keeping sensitive information protected.	(Accenture, 2018)
Blockchain technology allows anyone to transfer assets between entities without the risk of building silos that limit interactions among trading partners.	(Min, 2018)
The creation of the digital supply chain network will rely upon blockchain technologies to remove information silos and ensure data consistency, interoperability and security across different platforms within the entire supply chain whilst at the same time protecting the intellectual property of entities involved.	(Ghobakhloo, 2018)

The transitioning from the traditional supply chain to a digital interconnected network will most lilkely create new opportunities for cost reduction, communication and monitoring. Blockchains structure and ability mirrors that of the digital supply chain network and thus will play an instrumental part in being one of the technologies that facilitate this transition, showcased in figure 2-4 below which is continued on page 21 (Deloitte, 2019).



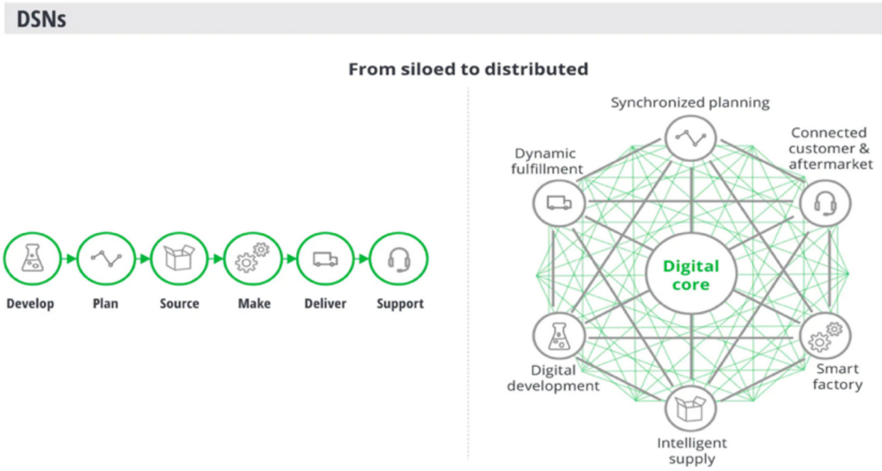


Figure 2-4 Role of Blockchain in SC Digitalization

2.2 Tracking and tracing

2.2.1 What is tracking and tracing?

Tracking and tracing plays an integral role in providing transparency to supply chains and facilitating information sharing. Tracking is the ability to locate a product at any stage the supply chain whilst tracing is the ability to identify a products' origin and characteristics along its supply chain journey. Tracking could be used to locate a product in order to withdraw it or issue a recall and tracing can be used to determine its source (Palamara, 2018; Dorp, 2004). Tracking and tracing can thus be defined as the ability to monitor products throughout the entire supply chain by recording information along the way that allows different actors to verify the history, location or characteristics of a product or digital asset (Villalmanzo, 2018).

Track and trace has a wide range of applications in the supply chain from anti-counterfeiting to optimization and synchronization of the supply chain and its main actors. It can also be used to monitor and improve quality of raw material, reduce costs and support inventory management. It can identify when products do not conform to standards, when processes are interrupted and identify products needed for recall. It is very useful for the identification of causes of non-conformance.

2.2.2 The need for tracking and tracing

New technology, market shifts and changing consumer habits are changing the way supply chains operate. Supply chain transparency is more important than ever. Customers are increasingly more conscious of the products they buy as they have a vested interest in their origin, characteristics and ecological impact. This is especially true in food supply chains where food safety is of critical importance. Health scandals and outbreaks of diseases are forcing food supply chains to track and trace their products. There have been various cases where lack of transparency has impacted consumers health and trust in supply chains. One example is from the UK where a major food supplier altered food safety records in order to trick customers into buying meat products that were past its sell by date (Safaryan, 2017). Another is from South Africa where a listeriosis outbreak was spread through contaminated ready-to-eat meats and resulted in the death of over 180 people (News24, 2018). Difficulties in tracing products back to its origin, created long delays in finding the source of the disease.

In this case, if a supply chain traceability system was in place to track and trace products in the meat supply chain, the issue would have taken much quicker to resolve and many lives would not have been placed at risk.

In other supply chains, there are many problems such as the influx of counterfeit goods. In an automotive example, fake car parts are entering the supply chain undetected. They end up being sold alongside original car parts and installed in vehicles. Counterfeit parts are extremely dangerous as they are not as durable and pose a threat to your vehicle and road safety (Jeep, 2019). By creating a unique product identify, products can be verified and tracked through the supply chain in order to determine if they are counterfeit or not.

The increased capability and ubiquitous nature of mobile technology such as smart phones, and digital identity technologies such as QR codes and RFID, provides methods for companies to track and trace their products more efficiently. There is a need for a system to bridge the gap between the physical and digital world, in order to give products a unique identity and provide abilities to determine its origin and characteristics (Palamara, 2018).

2.2.3 Digitalization of assets

In order for a product to be tracked and traced, a digital representation of that asset has to be created. This is a unique digital entity that is tied to a physical real world item. There are various technologies that can help digitize a physical product. Table 2-4 evaluates some of these technologies. Using these technologies listed in table 2-4, a physical product can be digitized, creating a unique product identity, in order to provide real time tracking and tracing for supply chain transparency (Gartner, 2018; Villalmanzo, 2018). A game changer in the field of asset digitalization has been mobile phones (Evrythng, 2014). Mobile phones have become ubiquitous and provides any user with a powerful handheld computer that contains digital sensors (such as an accelerometer, GPS, proximity, ambient light, optical, gyroscope, compass etc) and built in connectivity such as Wi-Fi, Bluetooth, GPRS, 4G and NFC. This allows almost anyone with a device, to scan/read, input, compute and upload data to a network regardless of location.

Table 2-4 Asset Digitization Technologies

Technology	Description
Barcode	A barcode is a method of representing data in a visual machine readable form. It stores data in a linear 1-dimentional way with a series of parallel lines or bars. When scanned they can show display information such as the manufacturers details and name of item or price.
QR Code	A QR or Quick Response code is similar to a barcode but instead of storing data linearly, data is stored in a 2D format. It contains data in both vertical and horizontal formats and thus stores much more information when compared to barcodes. It is more user friendly as anyone can create a QR code and attach them to products. They can also be scanned with a normal smartphone camera and does not require additional hardware to read or create them. QR codes are more durable than barcodes. They can also be created to trigger an internet action when scanned. They are cheap and easy to generate

RFID Chip 	RFID or Radio Frequency Identification is a technology where digital data is encoded into RFID tags or smart labels that can be captured by a reader through radio waves. The chip consists of an integrated circuit and an antenna which broadcasts information about the item. They do not require line of sight to be read such as with barcodes or QR codes and can also be scanned through surfaces. This makes them great for tracking and tracing applications. They are more technical and expensive when compared to QR codes but are better suited to supply chain environments where vast quantities of goods have to be tracked efficiently.
IoT sensors 	Sensors are devices that detect or respond to events or changes in their environment. IoT sensors refers to sensors that are connected to the Internet-of-Things which refers to devices that are interconnected to networks and able to communicate and transmit information. They can be used to scientifically monitor an assets' or products' environment or condition and transmit information about that for desired purposes. Popular IoT sensors include: temperature sensors, humidity sensors, pressure sensors, gyroscopes, accelerometers, optical sensors, proximity sensors, chemical sensors and many more. IoT sensors in tracking and tracing can be used to monitor the condition or quality of a product throughout the supply chain.
GPS chips 	GPS or Global Positioning System is a satellite based radio-navigation system that can determine the position or path of a GPS enabled device anywhere on earth.

Using current methods, digital data relating to physical products can be captured and stored by a supply chain company. The challenge however, is when that data has to be shared with other parties in the supply chain (Villalmanzo, 2018).

2.2.4 Problems with Current Approaches

There are many current approaches that deal with supply chain issues related to transparency and traceability. One such current approach is when companies place a chain of responsibility over their suppliers. A company will place responsibilities and guidelines on its first tier supplier which in place is trusted to regulate the 2nd tier supplier and so on. In this approach companies place trust in the hands of a 3rd party to ensure that its standards are met. However, this method is limited as it only effectively stretches to the 1st or 2nd tier suppliers. In addition, a high level of trust is required in order for this to work. While it might be a sufficient method to ensure trust and transparency between two or three companies, the further one moves down the supply chain and the more partners become involved, the more difficult this method becomes to regulate.

ERP (Enterprise Resource Planning) systems are capable of data capture and tracking products as they move through company processes. However, ERP systems are limited. They are not sufficient at capturing the required data and is usually limited to a certain company or section of the supply chain. ERP systems are housed in 'silos' and do not extend throughout the supply chain.

Using technologies such as sensors, barcodes and RFID, data can be collected and recorded at various stages of the supply chain. These technologies have been integrated into many current track and trace systems. There are however many problems with these methods that make them inefficient and not effective for tracking and tracing. There is a lack of data standards across the supply chain in terms of data sharing, recording and entry. There are also mismatches in information processes and technology capabilities between different partners. The main problem is that they use different technology systems, standards, tools and often have fragmented relationships (Potts, 2018; Pizzuti, et al., 2013; Villalmanzo, 2018). This means that traditional tracking and tracing solutions only work for certain portions of the supply chain and products are not effectively communicated between all the partners and stages involved.

2.2.5 Blockchain technology for tracking and tracing

Blockchain is seen as a technology with great potential to address the current problems of tracking and tracing and to deliver a truly reliable end-to-end track and trace solution for supply chain companies (Francisco & Swanson, 2018; Villalmanzo, 2018). It provides a decentralized secure database where information can be collected and stored along the supply chain by authorized partners. In this way blockchain enables a shift from traditional data management, which was carried out in silos, to a common distributed data ecosystem that that places trust in the system instead of controlling individuals.

Using technologies such as QR codes, barcodes, IoT sensors and RFID, physical items can be digitized by linking the products' physical identify to a transaction on the blockchain. This creates an immutable ledger that houses the products' entire history of its journey through the supply chain. Every actor in the supply chain has full visibility and as this is a shared system, issues can be tracked and resolved much faster.

One of the most important applications is in food traceability (Villalmanzo, 2018; Accenture, 2018). Blockchain can allow companies to efficiently record and share data in the food supply chain. How this works is as follows: A digital identity is created for a food item using a technology such as a QR code. This code will contain information such as the farm of origin, expiration date, quality, batch number, date, factory and process date, certificates, storage temperature etc. As the product moves from the farm to the retailer, information at each step is collected, validated and stored on the blockchain using a method of consensus. Thus, a transaction is written to the blockchain each time the product moves up the supply chain. This ends up creating a digital ledger that contains the full history of the product. When the product arrives at the retailer, this information can be verified as correct. By scanning the QR code for example, the full history of the product is shown which can verify: where it was, its origin, characteristics, shipping dates, temperatures it was stored at much more information related to its provenance, characteristics and journey. A visual representation of this process is provided in figure 2-5 , adopted from (Van Rooyen, 2017)

From a company or supply chain perspective, its provides complete supply chain visibility allowing companies to streamline their processes and resolve issues faster. For example, if an outbreak of a food related disease occurs, it may take weeks to track down the origin using conventional methods. With blockchain, that same process can be done in a matter of minutes or seconds. From a consumer perspective, blockchain tracking and tracing improves customers trust. It offers them the ability to verify the nature and characteristics of the products they buy.

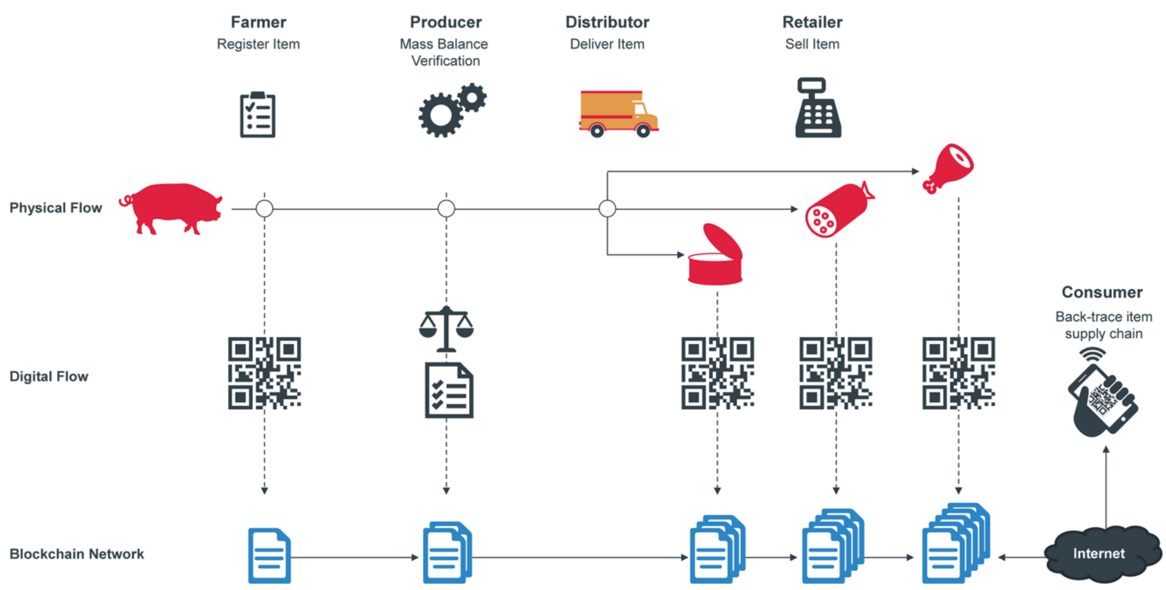


Figure 2-5 Blockchain track & trace example

2.3 What is Blockchain technology?

This section will examine the characteristics of blockchain technology, how it works and its significance for industry applications.

2.3.1 A Description of Blockchain technology

What is blockchain technology? There are numerous descriptions by many authors, yet there is no internationally agreed upon definition (Zile & Strazdiņa, 2018). Many point out that the reason for this is due to the fact that the technology is not yet fully understood and thus has not been clearly defined. Blockchain has become known to the world through Bitcoin, its most notable and well understood application. Many authors thus use the example of the Bitcoin blockchain to explain the technology in terms of transaction networks and consensus (Zile & Strazdiņa, 2018). For example, the oxford dictionary defines blockchain as '*A system in which a record of transactions made in bitcoin or another cryptocurrency are maintained across several computers that are linked in a peer-to-peer network*' (Oxford, 2019).

The scope of most definitions are limited to within the cryptocurrency aspect of blockchain. In reality, the technology has far wider range of forms and applications (Viriyasitavat & Hoonsopon, 2019). There are many different types of blockchains and as the technology is nascent, many new ones are still under development. This makes it difficult to formulate one universal definition. In attempting to define blockchain, the key elements from different definitions and descriptions will be used to give an overview of what the technology is, how it works and why it is different to a traditional database.

Blockchain is a specific type of distributed ledger technology. It contains a record of transactions, much like a ledger in a bank, that consists of a list of transactions grouped together in blocks. These blocks are interlinked to form a chain, hence the name blockchain. The record of transactions (ledger) is maintained by a network of interlinked computers, each having an identical copy of the records.

This network facilitates secure and transparent peer to peer transactions (which can contain money or information) without the need for a trusted intermediary (such as a bank) to maintain the network. As blocks of transactions are cryptographically linked to one another, transactions cannot be changed or deleted without invalidating the rest of the chain. Thus blockchain provides complete immutability and auditability of transactions.

Most academic and industry definitions include the terms immutability, auditability, transparency, distributed database and no trusted intermediary (Viriyasitavat & Hoonsopon, 2019). Below is a list of different statements from different authors made about blockchain.

Table 2-5 Blockchain Statements

Statement	Author
Bitcoin is the first and most famous application of blockchain technology where money can be transferred immediately in real time from one place to another at low costs and in a matter of minutes/seconds instead of waiting days/week and using various intermediaries.	(Swan, 2017)
Blockchain is an ordered list of blocks that contain transactions which can involve both monetary and information transactions. Each block contains the hash of the previous block's representation thus creating a linked chain. In this way, historical transactions in the blockchain cannot be changed without invalidating the chain of hashes before it. Combined with computational constraints and incentive schemes for block creation this can prevent tampering and information on the blockchain.	(Lu & Xu, 2017)
Blockchain makes up a distributed ledger, the control of which may be dispersed among several different computers in the network thus eliminating the need for trust towards a central database or administrator. In other words, blockchain is a distributed database comprising records of transactions that are shared among participating parties.	(Nowiński & Kozma, 2017)
A technology that enables immutability and integrity of data in which a record of transactions made in a system are maintained across several distributed nodes that are linked in a peer-to-peer network.	(Viriyasitavat & Hoonsopon, 2019)
Blockchain is the technology behind bitcoin. Money can be transferred without the need for a trusted intermediary or central authority. The term blockchain refers to its data structure which consists of a ordered list of blocks where each block contains a list of grouped transactions. Each block is linked to the previous block by containing the hash representation of the previous block. In this way historical transactions cannot be deleted or altered without invalidating the chain of hashes. Combined with computational constraints and incentive schemes on the creation of blocks, this can in practice prevent tampering and revision of information stored in the blockchain	(Xu, et al., 2017)

2.3.2 Operation

As noted, blockchain is a complex technology that is poorly understood. It is constantly evolving as new architectures, use cases and platforms are being developed. There are many different architectures, platforms and modes of operation, all with unique characteristics. These different 'ideologies' stem from the original public blockchain that lied behind the operation of bitcoin. The problem that Satoshi Nakomoto solved (through Bitcoin) was to enable trust in a distributed system of untrusted actors. More specifically, the problem of creating a distributed storage of timestamped documents where no party can tamper with the content of the data, or the timestamps, without detection (Lu & Xu, 2017).

According to *Gatteschi et al.* (2018) blockchain can be represented as a long DNA chain that increases in size and length when new transactions are added. Transactions are grouped together in blocks which are interlinked. Each block references back to the previous block, creating this sequentially linked chain. This chain is maintained by a network of nodes, validating transactions and adding them to new blocks in a process known as mining. To better understand blockchain, consider the process where persons engage in a transaction on the bitcoin network. This is illustrated on a high level in figure 2-6, adopted from (Nowiński & Kozma, 2017).

In this example, person A engages in a transaction with person B. This transaction is broadcasted to the entire network of nodes, making up the blockchain network. The transaction is digitally signed using secret information which insures that it does actually come from person A and that it cannot be altered by someone else. Other nodes in the network check that this is true by analysing that digital signature. They verify that person A can engage in the transaction, (does he/she have enough money for example) and consequently add this new transaction to a new block. This new block contains a list of many other transactions that are to be validated and added to the chain. The block has a header in which a summary of these transactions is stored in the form of a hash. The hash is a mathematical function that maps a given set of data to a fixed size sequence of symbols. The hash is thus a representation of the transactions in the block.

To add a new block to the blockchain, nodes engage in a process known as mining, a challenge to solve a complex mathematical problem. Nodes have to find a random value that, when combined with the hash of the transactions, and the previous blocks header, will produce a certain result. When a node finds a possible solution, it broadcasts it to the entire network which checks the validity of the answer. It is easy for nodes to validate that a given answer is correct and does not require the computing power to produce the answer initially. If the majority of the nodes agree on the result, the block is considered valid and is added to the chain. Each node then receives an updated copy of the blockchain ledger. The node that calculated the correct answer, and adds the block, is given a reward which incentivises the mining process.

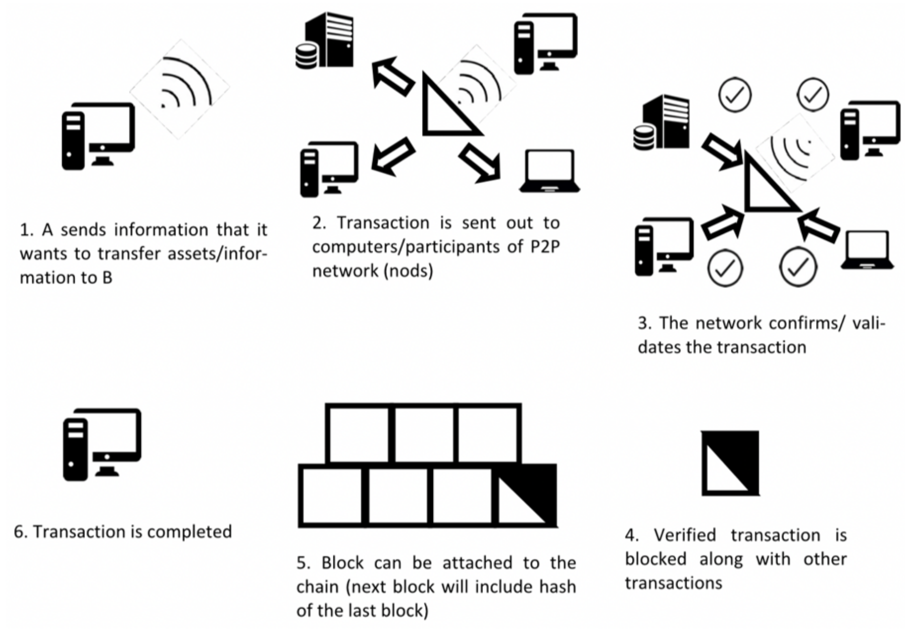


Figure 2-6 High level overview of a blockchain transaction

This reward could be, for example, a payment of cryptocurrency. If any transactions are changed, the hash changes and thus the block is invalidated as it does not link up with the rest of the chain. This is why blockchain is such a secure method of storing data.

The process of reaching an agreement on a new block and adding it to the chain is known as a consensus mechanism. There are many different types with advantages and disadvantages and suitable use cases. In this example, proof of work was used to illustrate the process but there are many other mechanisms of reaching agreement between a network of untrusted nodes.

2.3.3 Distributed ledger vs Blockchain

The terms distributed ledger and blockchain is often used interchangeably, however there are distinct differences between the two. Distributed ledger is the general form of the technology and blockchain is a more specific form with additional detail (blockchain is a specific type of distributed ledger). Both refer to the concept a ledger file that keep tracks of asset ownership. The four features that characterise distributed ledgers are: i.) a transaction database shared among network members that is ii.) updated by consensus, with iii.) records timestamped with a unique cryptographic signature, maintained in a iv.) tamper-proof auditable history of all transactions. Blockchain adds the additional feature of sequential updating of database records, per chained cryptographic hash linked blocks, where each blocks hash refers to the previous block, linking blocks into an immutable chain of transactions, hence the name blockchain (Swan, 2017). Every blockchain is a distributed ledger but not every distributed ledger is a blockchain.

2.3.4 Properties, advantages and disadvantages

Blockchain has a number of different advantages and disadvantages. In the following tables, its different properties, advantages, disadvantages and specific industry advantages are detailed (Lu & Xu, 2017; Lo, et al., 2017; Christidis & Devetsikiotis, 2016; Treiblmaier, 2018).

Table 2-6 Blockchain properties

Blockchain properties
- Data redundancy (each node has a copy of the ledger).
- Immutable data (data cannot be altered or deleted).
- Transparency of data (data is publicly visible to the network).
- Immutable chain of cryptographically signed historical transactions provide non-reputation of data (I.O.W there is no denying the authenticity, ownership or origin of data).
- Transactions are recorded in sequentially ordered blocks, the creation of which is ruled by a consensus mechanism.
- Transaction requirements are checked before being validated.
- Decentralization of decision making and distributed processing.
- Peer to peer transmission.
- Transparency with pseudo-anonymity and non-repudiability .

Table 2-7 Advantages of Blockchain

Advantages of blockchain	
- Everyone can view data transactions.	- Automation with smart contracts.
- No loss of data.	- Tolerates node failures.
- Trust between parties who might not trust each other.	- Transparency, verifiability, auditability of network transactions.
- Can be used between different actors who can all read and write to it.	- Availability of data, network consensus, security, enforcement, authenticity.
- Guaranteed transparency.	- Reduce workload and ensure traceability.
- Decentralization – can run without authority.	- Reduce admin and increases cost efficiency.

Table 2-8 Disadvantages of blockchain

Disadvantages of blockchain
- Lacks data privacy as every participant can access all information on the blockchain
- Limits on the amount of data, transaction rates, transmission and latency
- Consensus mechanism such as proof of work is resource intensive
- Inefficient consensus mechanisms (proof of work)
- Data replication requires space and limits storage space.
- Slow to add and process information
- Immutability and transparency could harm others
- Bugs in smart contracts cannot be changed

Table 2-9 Advantages for industry

Advantages for industry	
Provenance of data	Transactions involving assets and information across a number of parties, can be traced to its origin.
Trust	As trust is placed in the network, participants who don't have high levels of trust can engage in transactions without the need for a trusted intermediary.
Privacy	Even though blockchain is an open and transparent network, there are various mechanisms which can enforce privacy in certain use cases.
Security and data integrity	It is extremely difficult and almost impossible to corrupt the network as the digital ledger is distributed between thousands of nodes. No individual can make unauthorized changes.
Consensus	The system can reach agreement on the validity of data to be added to the network.
Availability	Data is always available to all nodes on the network and cannot be deleted.

Authenticity	The authenticity of data stored on the blockchain can be guaranteed
Accountability	Transactions are tied to the entities' identity and they can be held accountable for any information published on the network.

2.3.5 The Significance of Blockchain technology

2.3.5.1 A New Model for Trust

The reliance on trust has defined the way in which societies have evolved. Its significance might often be overlooked but it is an absolute necessary component for economic development (Knack & Zak, 2010). Trust enables people to willingly engage in exchanging value, to the benefit of those involved. Usually, if two people wanted to engage in a transaction, they would either have to know each other personally or make use of a 3rd party/intermediary to ensure trust. Blockchain technology threatens to disrupt the current trust model by enabling the possibility of secure direct transactions without the use of an intermediary.

Historically, organizations used databases as central data repositories to support transaction processing and computation. Control of these databases resided with the owner, who managed access to outsiders and was trusted to ensure that records would not be manipulated (Goldman Sachs 2016). Whilst the current centralised transaction system works well enough for most transactions, it still suffers the weaknesses of a trust based model. Completely non-reversible transactions are not possible and fraud cannot entirely be eliminated. The cost of mediation by 3rd parties increases transaction costs and limits small causal transactions (Nakamoto, 2008). In the centralized business model, companies can become global powerhouses, become corrupt, can be steered by small groups behind closed doors. Centralized databases can be hacked and intermediaries can take a slice of your privacy and money when operated through.

The reliance on intermediaries also increases process inefficiencies. For example, in the financial services industry, a simple cardholder authentication and clearing process can take 17 steps and involve 6 different parties (Cohen, 2017). These intermediaries are needed to: establish trust, verify identities, provide security and prevent fraud, process transactions and keep records, but do so at the expense of being centralized, valuable to attack/failure, increase costs and be notoriously slow (Cohen, 2017).

In the past, a decentralized database network seemed to be a solution, but was impossible due to technological limitations. That is until the launch of the Bitcoin cryptocurrency. This new form of electronic currency would allow two willing parties to transact directly with each other without the need for a trusted intermediary (Nakamoto, 2008). Due to the technologies complexity, this has resulted in significant hype and confusion in the industry and between experts.

There seems to be no consensus from experts on the future of cryptocurrencies such as Bitcoin. However, where experts do seem to agree is that the real value of cryptocurrencies lies in the technology underpinning it. In a recent Intelligence Squared US debate, the future of Bitcoin was debated by a panel of experts including notable investors such as Tim Draper, professors, authors and other experts on the subject. The panel was split over the future of cryptocurrencies such as Bitcoin but both sides agreed that Blockchain would play a significant role in industry and society (IntelligenceSquared , 2018).

2.3.5.2 Smart Contracts

Since the original application of Bitcoin, alternative and innovative Blockchain based platforms have been developed. One such platform, Ethereum, is set to contain Blockchain's true value. Ethereum's important difference is that a transaction's execution can be governed by a set of rules. It differs from the Bitcoin blockchain due to an additional layer on top that allows you to write programs that determines how a transaction is executed or under what conditions it may proceed. This is termed 'Smart Contracts' and is envisioned to redefine business models of the future. The Bitcoin Blockchain was designed only for transactions and not business logic. Having the ability to write self-executing contracts on the Blockchain will foster thing-to-thing, thing-to-person and thing-to-business relationships to change the nature of commercial authentication and identification (Furlonger & Valdes, 2017). In a smart contract, both parties can set the terms and conditions whilst at the same time, ensure trust and enforceability of the transaction. Experts are excited over the future of smart contracts, due to its widespread application. From healthcare and government, to business, internet of things and supply chains, smart contracts is said to be one of blockchain's 'killer applications' (Cohn, et al., 2017).

Blockchain and smart contracts are posed to simplify business processes by removing the need to rely on 3rd parties to ensure trust. The role of intermediaries is to establish trust, verify identity, keep records, prevent fraud and process transactions – all process that can be automated through Blockchain and Smart Contracts. Don Tapscott, CEO of the Blockchain Research Institute states that, "*What if every kind of asset from money to music could be stored, moved, transacted, exchanged, and managed, all without powerful intermediaries?*" (Tapscott, 2016).

2.3.5.3 Industry potential

In the book *'Blockchain: Blueprint for a New Economy'*, author Melanie Swan explains that Blockchain is one of the worlds 'leapfrog technologies'. The potential benefits and uses of Blockchain stretch beyond just financial and economic systems, it also extends to political, humanitarian, social, scientific and business domains. It is unique in the fact that it does not require users to trust each other and uses algorithmic self-policing to regulate the system and prevent fraud (Swan, 2015).

Technology research and advisory company Gartner has published many reports and held webinars on Blockchain. According to their findings, blockchain is evolving from a digital currency to a platform for digital transformation. Businesses in areas including government, healthcare, education, manufacturing, energy and supply chains, cannot ignore its role in future business operation models.

> *This is not just a new technology to improve existing transaction mechanisms; Blockchain provides greater levels of security, it creates new forms of assets, and it offers unquestionable provenance of anything conveyed over the network. Financial services was the first industry sector to recognize the technology's promise, particularly its potential for cost reduction (for intercompany reconciliation, for example). However, Blockchain technology has applicability to many business areas including government, healthcare, education, manufacturing, energy and supply chain* (Furlonger & Valdes, 2017).

2.3.6 Applications

Blockchain was created in 2008 as the technology behind the Bitcoin cryptocurrency where transactions are immutable in a publicly verifiable way. This has allowed money transfer between parties without relying on 3rd parties. As time passed, the actual technology behind blockchain became of interest as it was discovered it has potential use cases in many different environments and applications. Blockchain is often described as having three phases of evolution (Swan, 2015; Nowiński & Kozma, 2017). Phase 1.0 is the revolution of money and transactions with cryptocurrencies such Bitcoin, Ethereum and Ripple. Phase 2.0 refers to applications in industry related to information transfer and digital finance, most notably with smart contracts and automation. These applications include supply chains, financial services, smart utilities etc. Phase 3.0 involves applications beyond finance, market and economic uses with the development of digital societies and governance structures. These can include areas such as government healthcare, science and education to name a few. Table 2-10 below highlights some current applications.

Table 2-10 Popular blockchain applications

Popular applications of blockchain technology	
- Personal data management	- Commerce
- Intellectual property	- Supply chain
- Finance trading betting	- Services
- Software and internet	- IOT
- Government	- Healthcare

Besides the financial industry, the sector that has seen the most amount of attention and investment for blockchain is the supply chain sector. The complex nature of supply chains and the transaction interactions between different parties can greatly benefit from blockchain technology. Many different use cases within supply chain have been identified such as the verification of counterfeit goods, tracking and tracing of assets, verifying the origin of products and overall food traceability, to name a few (Gatteschi, et al., 2018).

2.4 The blockchain supply chain

2.4.1 Suitability of blockchain to the supply chain

According to the textbook definition, a supply chain consists of all the parties involved, directly or indirectly, in fulfilling a customer request (Chopra & Meindl, 2013). In short, a supply chain involves all the processes, across all parties, involved in producing a product – all the way from raw materials through to retail. Thus supply chains have to keep track of products and information across a complex network of intermediaries and aim to do so as efficiently as possible in order to generate value.

Experts agree that supply chain is one of the best suited applications for blockchain. An evaluation into the suitability of applying blockchain has revealed that supply chains and identity management are two of the best suited applications for blockchain technology in practise (Lo, et al., 2017). A survey estimates that 42% of companies in the consumer goods sector will spend more than $5 million (R75 million) on blockchain technology solutions for their supply chains (Lo, et al., 2017).

Supply chains are by nature some of the most complex multi-party systems that span across many different participants such as farmers, suppliers, manufacturers, factories, distribution and retail. Data transparency across these are highly desired so that participants are aware of the sequence and history of the products in the supply chain. Transaction history and data immutability enables supply chain actors to trace a products entire history back to its origin. This is useful for auditing the condition of the product in real time. Many current supply chains, which are paper-based, are not updated in real time which results in administrative and physical delays. Supply chain is a promising area for blockchain-based applications. It is clear that blockchain represents an opportunity to efficiently manage supply chain data across a complex supply chain network (Mao, et al., 2018).

2.4.2 Blockchains Unique Value

One of the most asked questions regarding blockchain in this context is, '*why do you need blockchain when there are existing IT systems and solutions in place?*' In short, blockchain enables new functions that did not exist before, or were before possible by using traditional methods. Kairos Future, a Swedish technology research company published a report in which they outline the four aspects that make blockchain key to the digitalization of supply chain and tracking and tracing (Kairos Future, 2017).

Digital units near impossible to copy

If you want to make a digital representation of a physical product or asset in the supply chain with specific characteristics, it's important that that digital representation cannot be copied or manipulated. As blockchain solves the 'double spending problem' it is impossible to create a copy of the digital file. This means that throughout a products journey in the supply chain, its digital representation describing its characteristics cannot be duplicated or altered. A central data-base can accomplish the same feat, but complete trust has to be placed in those maintaining it. With blockchain, the product can pass through a number of different parties, trusted or not, without there being any risk to its digital representation being altered.

Digital files that cannot be manipulated

With traditional systems it is very difficult to know if a file has been manipulated. Traditional systems can have rules that track changes of files but that places the trust entirely in those enforcing the system rules. There is no practical way for a manager, organization or auditor to track changes, or to know who made certain changes to digital files and transactions. Blockchain technology now makes it possible to ensure authenticity and originality of a digital. Blockchains unique hashing technology enables this feature that has never before been possible in traditional systems. This means that it is the only technology in existence that can make secure, trustworthy digital representations of a physical item, and maintain a complete record book or ledger about it. This feature is what sets blockchain apart from previous IT systems in the supply chain.

Digital processes that can't be manipulated

A 3rd problem that blockchain solves is in securing processes. For example, consider a process where a group of different actors have to confirm what they are doing at certain stages in the supply chain according to an agreement. If certain conditions were not met, the supplier needs to know who was responsible and exactly where those conditions were that weren't met. Securing processes is crucial to the development of digital supply chains. This is especially important in food supply chains where sensor data collect information valuable to ensuring the safety and quality of food. Blockchains ability to keep a secure digital ledger that is auditable and traceable is instrumental to enabling secure supply chain processes.

Low barriers to entry

The last important feature of blockchain is that the three aspects described above can be integrated at low cost. It is often at the lower end of the supply chain where actors have very limited IT capabilities. In the food supply, chain this will be the farmers or suppliers of raw goods for example. A system requiring each actor to have an Oracle or SAP solution with database integration is not possible and will never be realized in practise. Blockchain on the other hand makes it possible for actors across the entire supply chain spectrum to enter trustworthy data to the system. For example, farmers, truck driver or fishermen in the sea sending data via smartphones. Data and processes cannot be manipulated because of blockchains hashing and digital fingerprint technology which will also reveal if any attempts to jeopardize the data was made. This means with blockchain, every actor can view and update a complete digital record for a product as it moves through the supply chain system.

2.4.3 Benefits

A conference presentation on the latest advances in blockchain supply chain, which took place in Frankfurt, highlighted the eight major benefits that blockchain will have on supply chains worldwide, shown in figure 2-7 (von Perfall, 2019). Beyond this there are many different internal and external advantages presented by blockchain for use cases involving supply chain tracking and tracing. Table 2-11 highlight some of these benefits (Palamara, 2018).

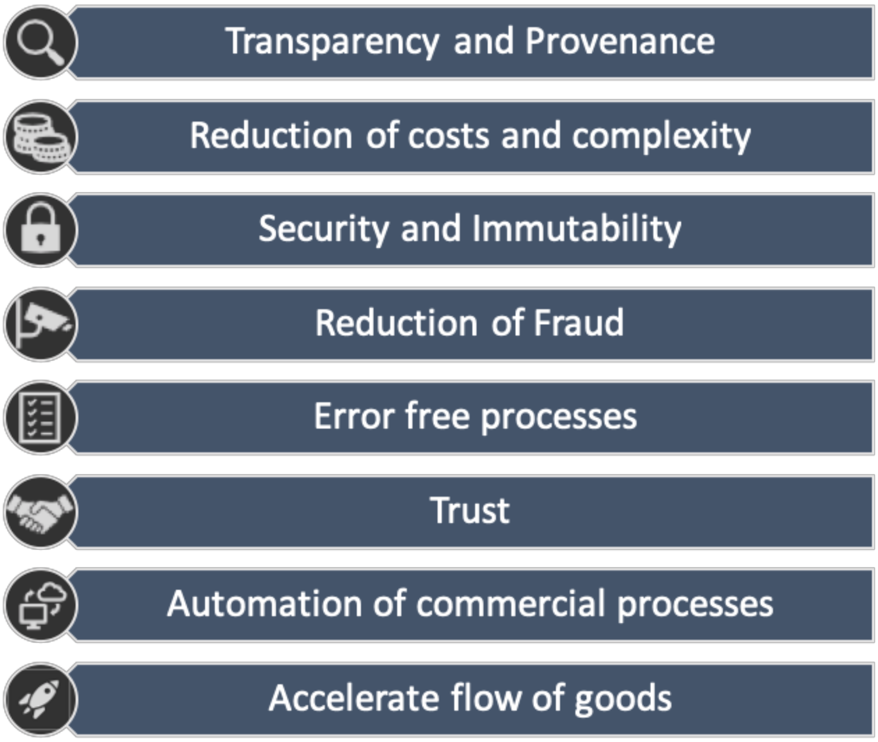


Figure 2-7 Blockchain advantages for supply chain

Table 2-11 Practical benefits to the supply chain

Practical benefits brought on by blockchain technology		
Internal	- Avoid a documents duplication. - Speed up the recalling and withdrawals procedure. - Remove cost of intermediaries.	- Improvement of quality control. - Improvement of the replenishment planning process.
External	- Fight fraud and black market. - Prove the ethical and environmental behaviour of companies. - Limits the companies collusion.	- Protects data. - Avoid the double spending of certifications.

2.4.4 Barriers to adoption

Blockchains are a relatively nascent technology that has received large amounts of press and hype, much of which is attributed to bitcoin (Scriber, 2018). Because of this, blockchain has been applied to many different use cases and problem spaces across a vast array of industries, many of which are not aligned to the promise or benefits of the technology. It has often been mentioned that blockchain is an innovative technology, searching for a use case (Risius & Spohrer, 2017).

Tribis, et al. (2018) identifies four barriers to blockchains adoption in industry.

1. Regulation conformance and legal barriers that limit the application of digital currency payments: There is a lack of common standards for completing transactions.
2. Adaptability and adoption: there is a general lack of understanding of how it works that acts as a barrier for bringing different parties together to be part of such a system
3. Scalability and size: the majority of proposed blockchain frameworks and systems were only tested in small scale controlled environments. There are many different challenges that will emerge when it is applied to a large environment.
4. A high degree of digitalization and IT computer systems is required.

Palamara (2018) goes further and isolates specific barriers that are applicable to supply chain tracking and tracing applications. The results are listed in table 2-12.

Table 2-12 Barriers to blockchain adoption

Barriers to blockchains adoption in Supply Chain Tracking and Tracing		
Operational	Easiness to imitate QR codes or NFC tags. The nature of items affects the choice of IOT devices used to track products.	Tracking components in complex products could be difficult because there could be reiterations of the same components.

Strategic/tactical	Impact in the cost structure not clear.	Lack of existing standards and legal rules.
	It requires full participation from every actor in the supply chain.	It requires the honesty of every company.
	Difficulties concerning the involvement of certain types of companies.	

2.5 Supply chain case studies

There are many different blockchain supply chain case studies and pilot projects. In this section, a few notable case studies will be evaluated followed by a discussion on the current landscape of blockchain applications in the supply chain.

2.5.1 AZHOS: German blockchain based supply chain solution for the chemical industry

The idea for AZHOS came from the automation of chemical supply chains by adding IoT sensors to solve problems in Vendor Managed Inventory (VMI). This is where chemicals used by company A in a production facility, is stored in tanks belonging to company B in the form of consignment stock. Every few weeks, the tank is checked for its content and A pays B. This means that there is a delay in payment for B which results in large amounts of bound capital. AZHOS is aiming to solve this problem using sensors and blockchain technology.

Their aim is to automate supply chain finance. Sensors will measure the amount of chemicals that A uses from B's tank. Whenever the level decreases, the sensor notices the change and saves new data on the blockchain. The signal which would normally have resulted in a re-order of the chemical good now initiates an automated payment to B using a smart contract. Using Blockchain, companies who store chemical consignment stock do not have to wait weeks to be paid, bound capital is freed up instantly (Der Altcoinspekulant, 2019).

AZHOS has over 20 years' experience in supply chain automation and use the latest IoT sensor technologies. With blockchain they are now able to synchronise the flow of goods with the flow of payments. Real time inventory data is linked to processes in such a way that it can be used to automate instant payments using tokenized electronic money and connecting that to bank accounts. This results in instant payments based on consumption and the AOS token holder receives a share of the profit.

Table 2-13 Azhos case study characteristics

Case study facts	
Type of blockchain	Private/Permissioned
Platform	Quorum (Modified Ethereum)
Consensus	Proof of existence (proof of inventory)

Case study benefits	- Instant liquidity - Freed up capital - Automated processes

2.5.2 IBM MAERSK

One of the best known blockchain supply chain case studies is the IBM and Maersk case study. Maersk is the world's largest shipping container company and have partnered with IBM, one of the leading multinational IT companies, to revolutionize the shipping supply chain using blockchain technology. Ocean freight accounts for 90% of the worlds goods trade. The problem is that this industry is highly dependent on a flood of paperwork that is never digitalized (IBM, 2017).

For example, consider the case of shipping flowers overseas, a $105 billion industry with 700 000 metric tons shipped each year. Shipping information must pass through many different parties. One shipment can require sign-off from 30 different parties and include up to 200 individual communications. One lost form or late arrival could leave a shipment stuck at a port leading to the entire process taking up to a month to complete. The entire process can be digitalized using blockchain technology in which the shared public ledger can stretch across the various supply chain parties. Shipment information is added to the blockchain at each point. All approvals and certificates are submitted electronically and the blockchain confirms the transactions. These transactions can be executed on a smart contact which releases the shipment. The end customer signs to confirm the delivery and this information is again relayed to the blockchain. The revelations of such a system is that all parties in the flower supply chain has end-to-end visibility of the container's progress through the supply chain.

IBM claims that blockchain can help enable unprecedented, secure transparency across the global supply chain. Blockchain can help all parties involved in a shipment:

- Reduce or eliminate fraud and errors
- Improve inventory management
- Minimize courier costs
- Reduce delays from paperwork
- Reduce waste
- Identify issues faster

As noted in *O'Leary* (2017), all documents for shipping containers can be fully digitized and the containers tracked. The system uses a permissioned blockchain which according to *IBM* (2017):

- Provides each participant end-to-end visibility based on their level of permission.
- Each participant can see the progress of goods as they move through the supply chain, understanding where a particular container is in transit. Participants can also determine the status of customs documents, view bills of lading and view other data.
- Movement of original supply chain events and documents is captured in real time.
- No one party can modify, delete or even append any record without the consensus from others on the network.

Table 2-14 IBM case study characteristics

Case study facts	
Type of blockchain	Private/Permissioned
Platform	Hyperledger
Benefits	- Track and trace - Efficient management of information - End to end visibility

2.5.3 EverLedger: The tracking of high value assets

One of the most well-known and successful applications of blockchain technology is in the diamond supply chain. The start-up company Everledger uses blockchain technology to track the provenance of high valued assets on a global digital ledger. The technological solutions they deploy provides stakeholders with an immutable history of an assets authenticity, existence and ownership across supply chains. Everledger looks at problems involving provenance in high valued assets such as diamonds. Crime causes financial losses when provenance is broken, meaning the asset is not able to be traced to its origin. $45 Billion is lost annually to insurance fraud, $2 Billion is lost to jewellery fraud and over 65% of fraudulent claims go undetected.

Everledger created a blockchain the encrypts and tracks diamonds across its supply chain right from the mine to retail. Everledger uses a hybrid technical model of both public and private blockchains' to ensure security and transparency. Anyone can view and track a diamonds origin, which asserts transparency at every stage of the supply chain yet security is aided by the permissioned controls of a private ledger (Everledger, 2018). This ensures transparency and authenticity of goods traded, protects the provenance of high valued items, re-establishes trust in global trading marketplaces and reduces risk, theft, trafficking and fraud (Everledger, 2018).

The company has been widely recognized by the industry as the leader in real world application of Blockchain technology. This success has led to many of the industry giants looking towards blockchain to apply similar benefits to their supply chains. According to a 2018 Reuters news article, De Beers, the world's leading diamond company, plans to launch the world's first industry wide blockchain this year, in order to track gems each time they change hands right from the instance they are first mined (Reuters, 2018).

Table 2-15 Everledger case study characteristics

Case study facts	
Type of blockchain	Hybrid (public/private)
Platform	Hyperledger
Benefits	- Track and trace of high value assets - Ensuring provenance - End to end visibility

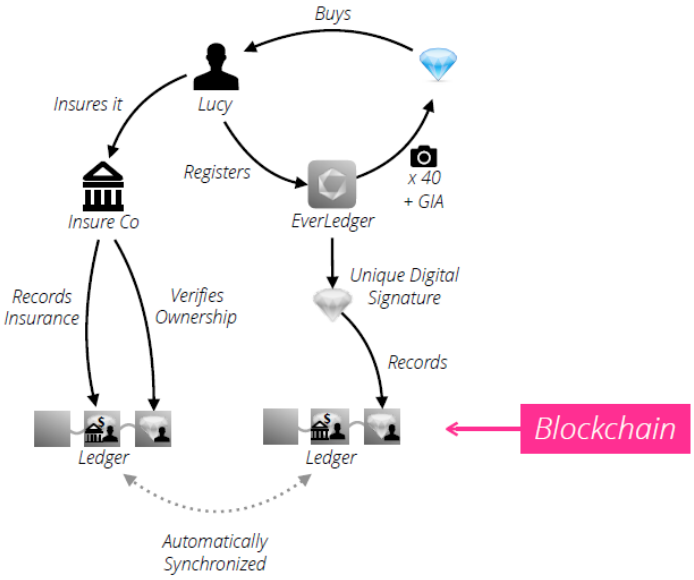


Figure 2-8 The Everledger blockchain system

2.5.4 Walmart: Transparency in the food supply chain

The challenge that prompted Walmart, America's largest mass retailer, to approach blockchain was the problem of food safety. When an outbreak of a food-borne disease happens, it can take days or even weeks to find the source (Hyperledger, 2018). Improved traceability can help save life's by allowing companies to act faster and develop better methods for tracking and tracing food through the supply chain.

Walmart chose blockchain technology for a decentralized food supply chain ecosystem. They partnered with IBM to develop a Hyperledger Fabric based blockchain for food traceability and tested this with a number of different products and stores. In one case, mangos were traced to some of Walmart's US stores, another involved tracing pork products sold in its China stores. In these cases, blockchain added significant improvements to the supply chain. For pork, in China, it allowed uploading of certificates of authenticity to the blockchain enabling more trust to a system which used to have serious issues. In mangos, the time needed to trace their provenance went from seven days to 2.2 seconds. Walmart now traces the origin of over 25 different products from five different suppliers using a system powered by blockchain and plans to roll out the system to more products.

Table 2-16 Walmart case study characteristics

Case study facts	
Type of blockchain	Private
Platform	Hyperledger
Benefits	- Tracking and tracing of different food produce - Ensuring provenance - End to end visibility

2.5.5 Blockchain in the art supply chain

Another interesting blockchain development involves an application in the fine arts. According to a Deloitte press release, a Blockchain proof-of-concept has been developed to solve traceability issues within the art supply chain. This system aims to verify the provenance and movements of artworks. The system will manage interactions between artwork from buyer to buyer. According to the TEFAF 2016 Art Market report, $63.8 Billion of art was sold globally in the past year through 38.1 Million transactions (Deloitte, 2016). Most of the stakeholders in this industry relies on paper certificates, which is easily lost, tampered with or stolen. As a response to these challenges, Deloitte Luxemburg's Blockchain solution can solve the current traceability and provenance issues by storing an artworks full history in a secure environment available to all. However, challenges still remain with ensuring that the artwork is an original and has not been replaced with a fake. According to Deloitte Luxembourg, techniques such as laser engraving, DNA spray and chip marking are being looked at as a more secure way of identifying a painting and generating a secure hash that will be stored on the Blockchain (Deloitte Luxembourg, 2016).

2.5.6 Blockchain in the fresh food supply chain

Multiple instances of health risks in fresh food supply chains have prompted stakeholders to use blockchain technology in their supply chains as a means to mitigate risk, and improve operational efficiency. In one such instance in 2017, the UK's largest supplier of supermarket chicken had to suspend production after an investigation found evidence of food safety records being altered. The investigation found that 'use-by dates' was altered to stretch the commercial life of chicken, thus tricking consumers into purchasing chicken that was actually past its use by date. The consumption of 'less than fresh' chicken can have dire health consequences for consumers.

This problem resonated with many similar scandals in fresh food supply chains and comes down to an underlying problem: the dependence of retailers on multiple suppliers to deliver products and ingredients. More accurately, the problem of lack of transparency and accountability across multiple supply chains. In the UK chicken case, none of the suppliers down the line could be monitored in real time. The top retailers could thus not identify the source of the manipulated use by dates, nor prevent the expired produce from reaching consumers. The only solution was to stop the entire supply, a cumbersome, expensive and inadequate solution (Safaryan, 2017).

Researchers are looking to solve issues surrounding complexity and distrust in Fresh Food supply chains with Blockchain. Despite the hype surrounding the technology, it has a real potential to fundamentally change supply chain processes. Fish suppliers John West started including codes on their cans of tuna to allow customers to trace products back to the fisherman. This initiative to enhance supply chain transparency added $22 million in sales.

An insight paper published by Logic2020 (2018) (a digital transformation consultancy) describes how a Blockchain solution will improve traceability and transparency in the apple supply chain. At the farm, the farmer logs data such as type of seeds, plant health, growth condition, quality at picking, picking date etc. onto the Blockchain. This creates a sequential log file of the product from plantation to harvest. As the apples are transported to a packing facility, their location, packaging date, storage conditions, quality certificate etc. is recorded onto the Blockchain. The distributor can access the blockchain to provide insight into factors such as how much inventory is available which aides in better planning. They also have a record of the apple's quality, certifications and storage conditions, all of which can be embedded into the product label, which displays its ledger file when scanned. When the apples are finally in the hands of the customers, it already has its entire history stored on the blockchain. Customers can be informed on the products source, certifications and nature, throughout its entire history. Besides generating trust in customers, all of these technological advancements means less food wastage, lower prices, reduced complexity and risk (Logic2020, 2018).

In figure 2-9, international management consulting firm Oliver Wyman outline an end-to-end blockchain enabled supply chain for dry aged beef. According to their research, the most crucial supply chain problems are: a lack of transparency due to inconsistent or even unavailable data, high proportion of manual (paper) work, lack of interoperability and limited information on a products lifecycle or transport history. They believe that the technologies' decentralized database can help increase supply chain transparency. In the dry beef example in figure 2-9, customers could validate every step that the beef has taken through its supply chain, simply by scanning a QR code. They conclude that Blockchain will be the backbone of supply chain digitization, and will improve customer experience, drive value and root out inefficiencies (Oliver Wyman, 2018).

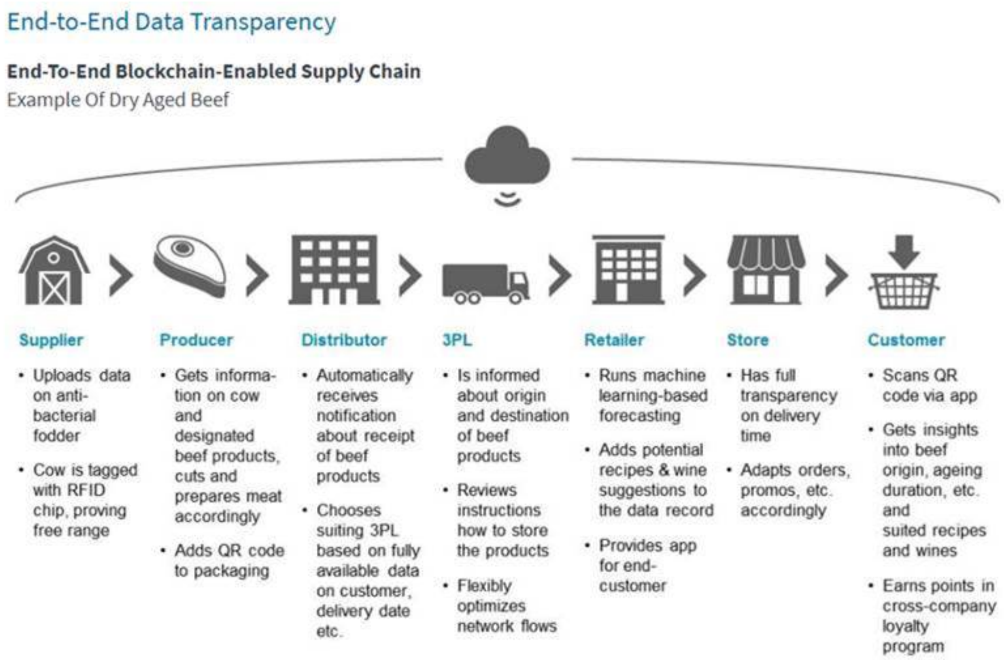


Figure 2-9 Blockchain end-end transparency example

When applying this insight to the case of chicken suppliers in the UK, customers would be able to access a chickens entire history by scanning a QR code on the packaging. All of the data related to its origin, feeding, culling, packaging, quality checks, aging, shipping and additional information can ensure customers of the quality at time of purchase. If a tamper proof ledger file of this information had existed, a health crisis such as the one mentioned would not have been possible, or at worst, easily mitigated. The suppliers would not have been able to alter the best before dates on their products without it going undetected (Safaryan, 2017).

There are still many barriers to this becoming a reality such as a general widespread understanding of the technology, investment and facilitation of implementation. Yet as fresh food supply chain problems persist and technological development improves, Blockchain based supply chains will move closer to reality. According to the world health organization, one-in-ten people fall ill due to food contamination every year and distributed ledger technologies present the best solution to this problem (World Health Organization, 2017).

According to a 2016 Gartner webinar on Blockchain's role in supply chains, the point is made that future business operating models cannot ignore the role that Blockchain will play. Blockchain's advantages directly present solutions to many problems supply chains face in terms of efficiency and complexity. That said, the technology is still very immature and by 2020, 90% supply chain Blockchain initiatives will remain proof of concept. Blockchain offers so much potential, yet we are not quite there yet (Gartner, 2016). The large scale application of blockchain technology coupled with the lack of foundational knowledge on its operation in supply chains presents an interesting research opportunity. Exploring this opportunity could contribute to practitioners in the supply chain environment as well as fill a research gap in academic literature.

2.5.7 Case studies discussion

By examining the above case studies and a wider range of examples in industry, a description of the current landscape of blockchain supply chain can be given. Generally, supply chain case studies focus on tracking and tracing. Supply chains aim to utilize blockchains ability to keep an immutable ledger of secure transactions across a network of untrusted participants to facilitate tracking and tracing of products, as they move from raw materials to retailers. There are four main benefits associated with blockchains use in supply chain tracking and tracing namely: visibility, transparency, provenance and automation, shown in figure 2-10 below.

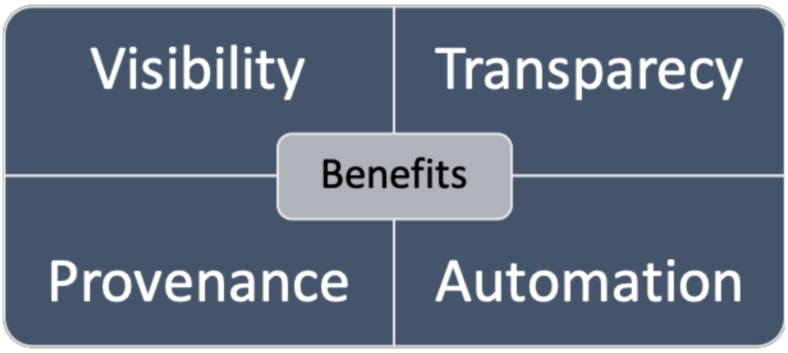


Figure 2-10 Main benefits from case studies

A number of different blockchain architectures are employed in the case studies, however it is clear that supply chain tracking and tracing cases prefer to make use of private permissioned blockchains (Palamara, 2018). An evaluation into the taxonomy of different blockchain case studies revealed that, although different approaches have been tried and tested, private/permissioned, and in some cases hybrid/permissionless, architectures are the preferred methods. Completely open and public blockchains, such bitcoin, are seen as a risk to exposing any sensitive information that may be transferred. Companies want some sort of mechanism to control who may or may not take part in the network. From a theoretical point of view, a hybrid architecture might be more suitable as it prevents the system from becoming traditional centralized one by having a permissionless blockchain with a degree of control for specific applications.

Generally there are two major platforms upon which the case studies rely namely Hyperledger Fabric and Ethereum. Hyperledger Fabric is one of the platforms in the open source Hyperledger umbrella project for blockchain related platforms, tools and solutions. The project is spearheaded by Linux, IBM, SAP and Intel – companies who are strongly involved in the supply chain industry. Thus, many companies who already use their services consult them for blockchain projects and case studies. Ethereum is an open source public blockchain platform and is also popular for use in supply chain tracking and tracing solutions. Ethereum can, much like Hyperledger, be adapted and configured to suite individual applications. The main difference is that Ethereum makes use of a public mode of operation whilst Hyperledger is private. Figure 2-11 showcases a taxonomy of existing platforms used by supply chain track and trace case studies, adopted from Palamara (2018).

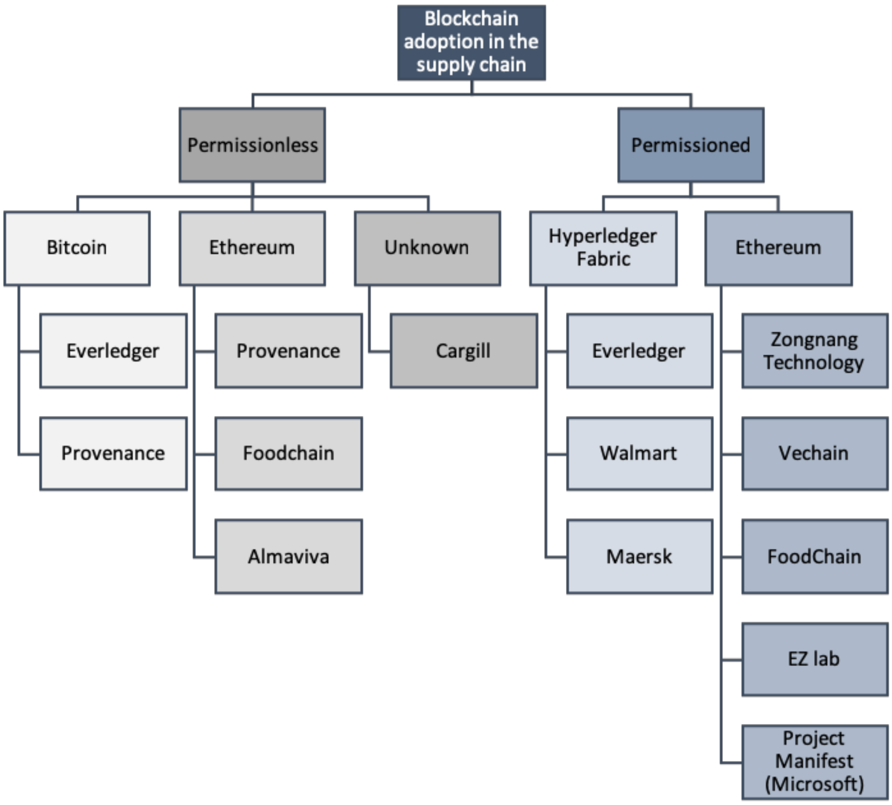


Figure 2-11 Taxonomy of blockchain cases in the supply chain

Another study was done comparing different blockchain tracking and tracing pilot programmes that address problems involving food traceability. Six different case studies were compared to understand their characteristics, successes and failures. Table 2-17, adopted from Accenture (2018), showcases the results of the study.

This study further highlights that Ethereum and Hyperledger are the two most used platforms for tracking and tracing blockchain applications. In the case of BeefLedger, Ethereum is used in its original form as a public blockchain. In the other 2 cases, it has been modified to work as a hybrid blockchain which maintains the benefit of a public blockchain but with an added layer of permissioned controls. This will be elaborated in later sections. The other cases are supported by IBM and Hyperledger fabric. In terms of data collection along the supply chain, the solutions make use of mobile technology, RFID chips, IoT sensors, NFC stickers and QR codes to connect data from the real world to the blockchain.

Table 2-17 Blockchain food traceability cases

	Provenance	WWF, Traceable Sea Quest	BeefLedger	Belagricola, IBM	Walmart, IBM	Accenture, Bill of Lading
Place	Indonesia	Fiji	Australia	Brazil	Central America	United Kingdom
Item	Tuna	Tuna	Beef	Grains	Mangoes	Containers
Platform	Unknown	Ethereum (hybrid) (Proof of Stake)	Ethereum with smart contracts (permission-less)	Hyperledger Fabric (permissioned)	Hyperledger Fabric (permissioned)	Ethereum with permissioned layer on top (hybrid)
Summary	Mobile, blockchain, and smart tagging to track responsibly caught tuna and certifications/ claims from catch to consumer, aiding proof of compliance to standards along the chain	IoT / sensors, smart tagging, and blockchain to drive out illegal fishing, make supply chains fairer and aid instantaneous auditing	IoT, blockchain, analytics, smart contracts, and digital tokens to track provenance, streamline payments, mitigate fraud risk, and provide transparency in sustainability	IoT and blockchain to track grains stored in warehouses for quality assurance, with the goal of optimizing grain trading with global exporters	IoT and blockchain to track mangoes through the supply chain, from farm to consumer, with the goal of identifying provenance and improving food safety issues	Blockchain to record events and transactions across multiple parties in shipment, provide real- time track and trace to align shipper and carrier of the load movement
Key Nodes	Local NGO, fisherman, supplier, retailer	Fishery, processing facility, exporter	Cattle breeder, grazier, feedlot, cattle agent, transporter, abattoir, distributor, retailer	Cooperative producers, warehouse originator company, rural credit bank	Farm, packing house, import warehouse, processing facility	Exporter, forwarder, export port, carrier, import port, importer
Data Tracked	QR codes & NFC stickers, actor ID, location, attributes or certification, fishing method	QR codes & RFID chips, temperature, certifications, vessel no., weight, actor ID, time stamp	PO no, price, weight, actor ID	Grain quality (ex: moisture level), actor ID	Batch number, farm origin, factory data, expiration date, shipping details, food safety audits / certificates	Data attributes across data sheets (e.g. bill of lading)
Key Impact	Not quantified	Not quantified	Not quantified	15% GM-free Soybeans added value (anticipated)	Traceability to point of origin went from 7 days to 2 seconds	Data attributes can be reduced by approximately 80%

Various key learnings were gathered from this study:

- A successful blockchain requires the identification of the right use case and partners.

- Existing paper-based tracking and tracing methods are slow, inefficient and costly with up to 70% of data being replicated.
- Blockchain can streamline and speed up information gathering operations and manage product data attributes.
- Blockchain can allow for clarity and transparency of relevant information to relative parties in real time.
- Sharing product data is key to establishing provenance of products.
- Key data points that defines a products identity need to be defined.
- It should be decided what data needs to be stored on chain vs off chain to preserve privacy of sensitive information.
- IoT sensors, smart tags and other data capture techniques are key for reliable standardized data capture.
- Blockchain must go hand in hand with the digitalization of information on the supply chain.
- Food traceability solutions must contain the use of traceability technologies that can record data such as location, time and nature.
- Interoperability between blockchain and enterprise systems needs to be considered.
- As every actor in the food supply chain needs to adopt the technology, it needs to integrate with its existing IT systems and add value in doing so.
- As data shared is tamper evident and accessible to all, it should be carefully considered what data is uploaded to the blockchain.

The figure below provides a summary of the findings from the different supply chain case studies. Use cases centre around the use of blockchain for tracking and tracing of products in the supply chain, especially in food supply chains as this is currently the best identified use. Overall, the goal is to provide provenance and supply chain visibility. Other advantages that are derived from this is more efficient processes surrounding information management.

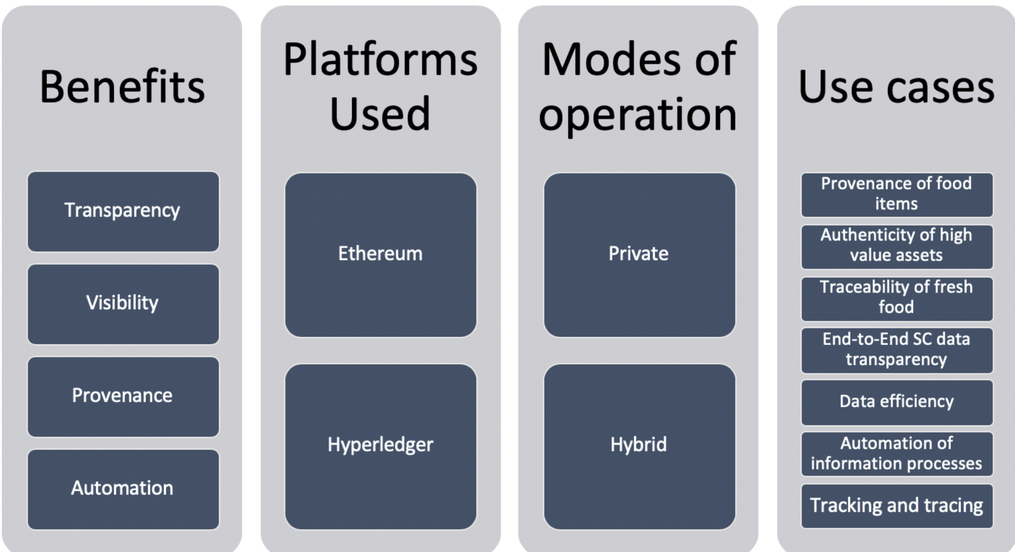


Figure 2-12 Summary of blockchain use cases in the supply chain

2.6 Latest technological architectures

At this point, the role of blockchain in supply chain tracking and tracing has been discussed and a brief overview of the technology has also been given. In this next section, a deeper analysis of the technology will be done. Important aspects such as the different blockchain platforms and architectures will be covered, along with comparisons between them. This is key to understanding the various technical considerations and decisions that must be made regarding blockchain. The subchapter starts with a description of how blockchain works, followed by the different blockchain technological aspects.

2.6.1 The Blockchain Architecture: a basic yet technical description

The name 'blockchain' reveals two key aspects of how this database is structured. The word *'block'* refers to the fact that data (related to transactions) is grouped together and stored together in 'packets of data' i.e. blocks. The word '*chain'*, clarifies that these blocks are structured and linked together in a specific order. The fact that block *'n'* is only linked to block *'n-1'* and *'n+1'*, is an important structural aspect that ensures data validity. A blockchain block contains a header and a block body, showcased in figure 2-13 and further explained in table 2-18. The content and significance of the block header and body is explained in table 2-18 (Zheng, et al., 2017).

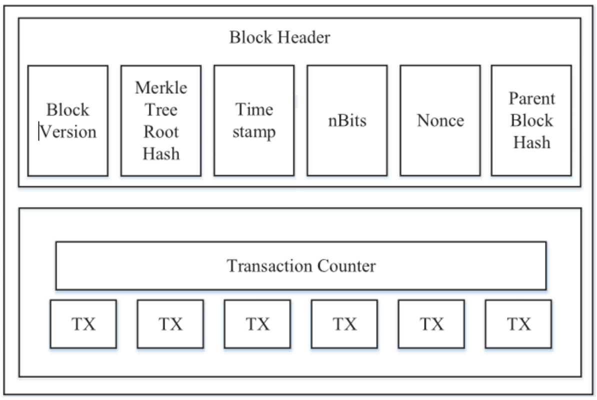


Figure 2-13 Blockchain header and body

Transactions between peers are recorded using a private and a public key. A users private key is used to confidentially sign a transaction where the receiving party uses the users public key to validate such a transaction. When a transaction is requested, it is broadcasted to neighbouring nodes who check that the transaction is valid before passing onto the next node. These transactions are validated in a system where no single node is trusted and there is no trusted middlemen (Christidis & Devitsikiotis, 2016).

Each blockchain network has a set of rules that it has to abide by, to in order to help decide whether incoming transactions are valid. This is called a consensus mechanism. There are many different types of consensus mechanisms and they will be described in more detail at a later stage. Transactions that have been validated by the network, during an agreed upon time interval, are ordered and packaged into a timestamped candidate block. A block is added to the chain when a majority of nodes in the network reaches consensus on the validity of the block (Nofer, et al., 2017). A transaction will pass through the entire network, and if all nodes agree that it is valid, the transaction is packaged alongside other transactions (in a certain time interval) into a new block called a candidate block. This new block has to be added to the existing chain of blocks. Nodes check that this block contains valid transactions.

Table 2-18 Description of blockchain block contents

Description of block contents		
Block Body	Transaction counter	Number of transactions written in current block.
	Transactions (TX)	The transactions occurring on the network.
Block Header	Block version	A set of validation rules to follow.
	Merkel tree root hash	Unique hash value of all block transactions.
	Timestamp	Current time as seconds in universal time.
	nBits – Target hash	Target threshold of valid block hash.
	Nonce	A random number verifying the hash.
	Parent Block hash	256 bit has value that points to previous block. Hash of previous block.

These transactions references to the previously verified block on the chain via a hash function, which is part of the validation process. A hash function converts a set of input data into an string of encrypted output.

When transactions are grouped together in a new block, this data is encrypted using an algorithmic hash function. As noted, this hash function produces a long string of numbers and letters from the input data that does not resemble the data in the block. The hash function is deterministic and will always be the same length and correspond directly to the input data. This is important as you cannot distinguish between hashes by looking at the amount of input data used. Any changes in the input data will result in a change in the hash. Computers work to decode and encode this hash in a process called mining. Processing these hashes requires large amounts of computing power. As explained, each block header has amongst others, a nonce and a target hash. The target hash is a 256 bit number found in the header. For the block to be added to the chain a miner has to produce a nonce that, after being hashed, is equal to or less than the one used in the most recent block accepted on the chain, i.e. the target hash. Miners compete with each other to solve this target hash which is a complex mathematical problem that involves many repetitions of guessing large numbers. The nonce is a random string of numbers contained in the block header that is difficult to guess.

A block is generated by taking the hash of the block contents, adding a random string (nonce) and hashing that block again. If this hash meets the requirement of the target hash, it is added to the chain. Cycling through this process is known as the proof of work where minors who solve it first is awarded in cryptocurrency.

To solve the target, the nonce is added to the blocks hash (jumbled up transaction data) to create a new number which is then hashed again. That hash is then compared to the target hash in the block header. The nonce is unknown to the miner and difficult to guess thus the miner will run through a large amount of numbers before solving it. If it meets the requirement of the target hash, the miner is rewarded with cryptocurrency and the block is added to the chain. The crypto reward provides an incentive for the miner to invest computing power to solve the problem.

Miners thus hash the data in the block, guess a nonce, rehashes that number and compares it to the target hash. This process is repeated many times until the right nonce is guessed that allows the hash to meet the requirements of the target hash. The block is added and the world view is updated. This process is represented in figure 2-14 below (Zheng, et al., 2017).

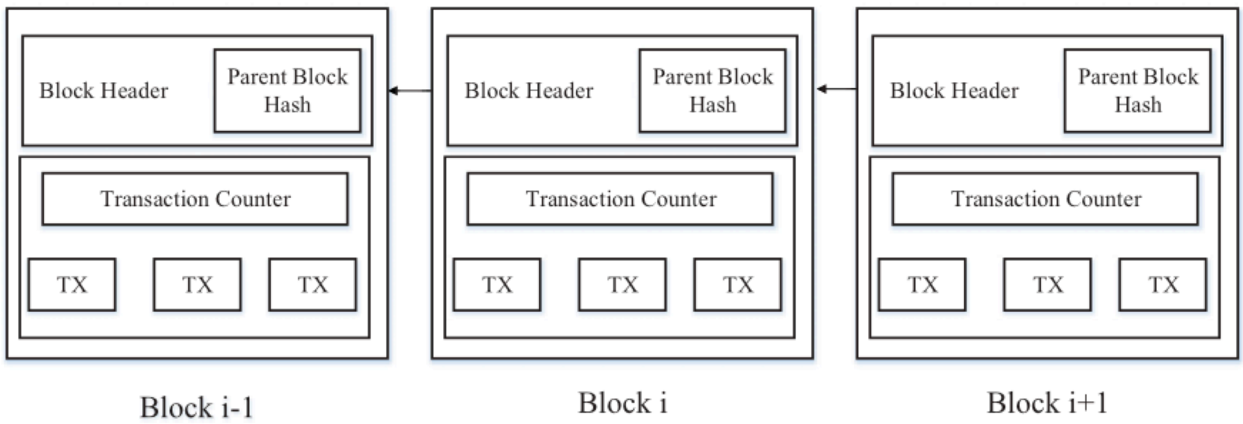


Figure 2-14 Example of the blockchain structure

2.6.2 Consensus mechanisms

Blockchain consists of a number of nodes that interact in the decentralized network. Not all of these nodes are trustworthy and there is no central node to decide which nodes are trustworthy, and which are not. Thus the challenge that is presented is: '*How does one form an agreement on the validity of a transactions in such a network?'* The answer is consensus mechanisms, central to the functioning of any blockchain.

Reaching a consensus among a network of nodes can be described by the popular computer science problem called the '*Byzantine Generals Problem'*. In this problem a group of generals in charge of the Byzantine army surrounds a city in a plan to attack it. Some of the generals will prefer to attack whilst others prefer to retreat. The retreating generals are traitors to the system as an attack would fail if only a certain part of the generals attack the city. The problem is to determine how many traitorous generals can the army have to ensure a successful attack operation (Zheng, et al., 2017).

In Blockchain there are more than one approach to combat this challenge, each with their own advantages and disadvantages. According to a KPMG publication on consensus, '*a consensus mechanism' is the way in which a majority (or in some mechanisms, all) of the network members agree on the value of a piece of data or proposed transaction, which then updates the ledger'* (KPMG, 2016). Another definition is '*A consensus protocol is computer protocol in the form of an algorithm constituting a set of rules for how each participant in a blockchain should process messages (say, a transaction of some sort) and how those participants should accept the processing done by other participants. The purpose of a consensus protocol is to achieve consensus between participants as to what a blockchain should contain at a given time*' (Chamber of Digital Commerce, 2016).

This means that a consensus mechanism is a set of rules and procedures a system subscribes to that maintains a coherent set of facts among the participating nodes. These algorithms allow different nodes to work together as a group even if a portion of them fail or are untrustworthy. There are numerous types of consensus mechanisms each with their own advantages and disadvantages. Each of these mechanisms must however guarantee the order and correctness of transactions and blocks (Hyperledger, 2018).

There are many different consensus mechanism used across different platforms. KPMG (2016) published a list of known consensus mechanisms across a variety of platforms:

- Proof-of-Work (POW)
- Proof-of Stake (POS)
- Delegated Proof-of-Stake (POS)
- Leader elected consensus
- Round robin
- N2N
- Federated consensus
- Proprietary consensus
- Consensus without mining
- Practical Byzantine fault tolerance (PBFT)

There are many different methods to reaching consensus as shown above. These mechanisms use different ways to solve the same problem and have different advantages and disadvantages. As the technology is nascent, many of these methods are still in development stages with new ones constantly being developed and tested. The plethora of methods mean that it is still not proven what the best method is in certain scenarios.

Proof-of-Work is the most well-known and well proven way of reaching consensus in a blockchain, as employed by Bitcoin. It is incredibly secure, well tested and has a clear incentive mechanism in place. However, as it uses large amounts of computational power it is not very efficient (Swan, 2017). It was calculated that the total amount of energy consumed by Bitcoin per year is equivalent to that of the entire country of Ireland (The Economist, 2018). Due to this, there have been a variety of other mechanisms developed to reach consensus without the inefficiencies of POW. Some of these include Proof of Stake, PBFT and BFT variants including consensus without mining mechanisms. These have low latency, require less computational power, have higher scalability, waste fewer resources and can improve security for smaller chains in more industry related applications (Swan, 2015).

Table 2-19 showcases a few of the relevant consensus mechanism that have been used in blockchain case studies in the supply chain (Zheng, et al., 2017; McDermott, 2019).

Table 2-19 Notable blockchain consensus mechanisms

Mechanism	Description
Proof Of Work (POW)	Most well-known and well tested. Uses mining to reach consensus and is used by bitcoin. Incredibly secure yet very inefficient.
Proof Of Stake (POS)	This mechanism abolishes mining completely. The creator of the next block, i.e. miner selection, is based on their stake (wealth) as well as a randomness factor. When compared to POW, POS can roughly be defined as: *'instead of treating consensus as 'one unit of CPU power equals 1 vote, it is instead 1 currency unit equals 1 vote'.* Instead of competition, POS randomly selects a node to compute the next block. There are no miners, there are only validators which are selected based on their stake (of cryptocurrency). The node chosen to validate the next block checks that all transactions are valid and receives a transaction fee when adding the block to the Blockchain. The question raised is, '*how can validators be trusted'?*

	There is a financial motivator in being trustful as validators will lose a part of their stake if they approve fraudulent transactions. As long as their stake is higher than the transaction fee we can trust them to correctly do their job. If not they lose more money than what they have gained. Proof-of-stake is more energy efficient than proof-of-work, has a smaller barrier to entry and is generally less expensive to implement. It is currently being considered for use in the Ethereum blockchain platform as a more efficient method as opposed to POW.
Delegated Proof OF Stake (DPOS)	A variant of the proof of stake system tries to combine proof of stake with proof of work characteristics. DPOS uses a decentralized voting process through what can be referred to as witnesses as a way to mitigate against a potential network centralization. The major difference between POS and DPOS is that stakeholders elect delegates to generate and validate blocks. Significantly fewer nodes are needed to validate a block which leads to a quick changeover time in validating blocks and approving transactions. Coin holders can use their balance to elect a list of nodes to be possibly allowed to add new blocks of transactions. Whilst POS is like winning a lottery, DPOS gives all coin holders more influence and ownership in a network.
Practical Byzantine Fault Tolerance (PBFT)	A mechanism designed for use in enterprise applications where members are partially trusted. This mechanism is commonly used in the Hyperledger platform. It is relatively simple, does not require any hashing power and is useful for storage systems. Two notable factors are that i) parties involved must agree on the exact list of trusted participants and ii) membership is set by a central authority. This may be more useful to the management of private digital assets than maintaining an open and pubic ledger. It offers high rewards, is very efficient and offers transaction finality.
Raft Based	Used commonly in the Quorum/Ethereum platform to achieve consensus. It is an alternative to Ethereum's POW mechanism. This is useful for closed-membership/consortium settings where byzantine fault tolerance is not a requirement, and there is a desire for faster block times (on the order of milliseconds instead of seconds) and transaction finality.
Istanbul BFT	A variation of the original PBFT mechanism. It is designed and more appropriate for hybrid like and consortium oriented networks such as used in the Quorum platform.

In a further study, an evaluation framework was developed to help practitioners evaluate and decide on choosing a mechanism. The different evaluation criteria is presented below in table 2-20 adopted from (KPMG, 2016).

Table 2-20 Evaluation criteria for consensus mechanisms

Evaluating consensus mechanisms		
Overall consensus methodology	- Underlying methodology	- Nodes needed to validate a transaction
	- Ownership of nodes	- Different timing and stages of consensus
	- Fault tolerance	- Validator nodes (number and type)
	- Data storage	

Governance, risks and control	- Counterparty risk - Risk mitigation measures - Types of nodes	- Enforcement of governance controls - Responsibilities and legal action - Access control and admin privileges
Performance	- Time to validate transactions - Scalability - Speed	- Volume and value - Number of fields per transaction - Synchronization
Security	- Digital signatures - Documentation - Network synchronization	- Transaction activity monitoring - Security testing and certifications - Preventing signature fraud
Privacy	- Verifiable authenticity - Data encryption	- Transparency and visibility into transactions
Strength of algorithm	- Library and HSM integration - System strictness	- Key generation and key lifecycle - Error monitoring
Tokenization (if applicable)	- Use of tokens - Transaction signing	- Asset tokenization and life cycle - Token security
Implementation approach	- Use cases being explored - Cost and time to implement	- Business case - Working partners

2.6.3 Public vs Private Blockchains

Public, private, permissionless, permissioned and hybrid are different terms used to describe the mode in which blockchains operate. The differences between them are extremely important and will dictate: how the blockchain works in its environment, who is allowed to join the network, what rights these individuals will have, what changes are they allowed to make and what data they can see. The differences between the terms are described below (Peh, 2018).

2.6.3.1 Permissionless

All nodes to have equal rights such as data access, creating transactions, validating transactions and producing new blocks. No permission is required to join the network as it is open to everyone that wants to join.

2.6.3.2 Permissioned

All nodes do not have equal rights with regards to: access of data, creating of transactions, validating of transactions and producing new blocks. For example in a permissioned blockchain, only a few nodes might be selected to produce new blocks in the network.

2.6.3.3 Public blockchain

A public blockchain is one which allows anyone to join, thus they are usually permissionless. The presuming assumption is that every node will be rewarded monetarily for their participation and performing their duty impartially. In the case of POW mining, the node that solves the next block is rewarded with the chains cryptocurrency. As there is a monetary incentive to behave, it is assumed that most participants will not be malicious, thereby facilitating decentralized trust. In plain terms, it is in the best financial interest of nodes to behave and support the system. Examples of public blockchains are Bitcoin, Ethereum and Litecoin. As mentioned, a public blockchain is usually permissionless but it is also important to note that a public blockchain can be configured to be permissioned.

2.6.3.4 Private blockchain

A private blockchain is a closed blockchain where privacy is preferred. Every participating node in the network is pre-selected and must be approved to join the network. The network is generally trusted and thus the incentive/motivation for a node to perform its duty might be something other than monetary rewards. In cases such as a consortium for example, a participating node could be implemented compulsorily ,due to a business or collaboration requirement. Notable private blockchains include the Quorum blockchain and those under the Hyperledger umbrella project such as Hyperledger Fabric Hyperledger Sawtooth. It is possible to have a permissionless private blockchain but most of them are usually permissioned.

2.6.3.5 Hybrid blockchain

Hybrid blockchains aim to address the disadvantages experienced by both public and private blockchains. Currently, decentralized public blockchains experience inefficiencies such as low transaction speeds. Smaller more private blockchains, on the other hand, are less decentralized and have much faster transaction speeds as consensus can be achieved faster. As decentralization is key to providing a trust less system, there is a dilemma: '*how can one have high transactions speeds without compromising security and decentralization?* If private blockchains become more centralized in order to scale, is it even worth using a blockchain in the first place?

A solution aiming to address this is the hybrid blockchain, which is a mix between public and private. Transactions occur at a high rate on their own private blockchain and only register on the public chain when necessary, for example when public verification is required. This will provide the immutable trust provided by the public blockchain, as well as the efficiency and scaling of a private blockchain.

2.6.3.6 Remarks on public vs private vs hybrid blockchains

Private blockchains are often more preferred for industry applications due to the difficulties experience in public blockchains such as handling privacy, control of governance and volatility. In a permissioned ledger, one avoids some of the issues mentioned above whilst still retaining some of the blockchain benefits. However, a private blockchain removes the economic component of decentralized trust and consensus incentives found in public chains. Instead, nodes perform their function not for a monetary reward but because others on the network hold them accountable. Private blockchains remove the need for miners, where a transaction is only considered final when it has spread to all nodes in the network, a mechanism which limits block size and transaction speed (Peck, 2017).

Comparison studies have been done to evaluate the differences between public and private blockchains. In table 2-21 and 2-22, public, private and hybrid blockchains are contrasted and compared, adapted from Viriyasitavat & Hoonsopon (2019) and Zheng, et al. (2017).

Table 2-21 Technical comparison between public, private and hybrid blockchains

Type	Cost per transaction	Performance		Trust of system	Scalability	Maintenance	Openness	Efficiency
		Throughput	Latency					
Public	High	Low	High	High	High	Low	High	Low
Private	Low	High	Low	Low	Low	Medium	Medium	High
Hybrid	Medium	Medium	Medium	Medium	Medium	High	Low	High

Table 2-22 Characteristics of public, private and hybrid blockchains

Property	Public	Hybrid	Private
Consensus	All miners	Selected set of nodes	One organization or consortium
Read permission	Public	Public or restricted	Public or restricted
Immutability	Near impossible to tamper	Possible to tamper	Possible to tamper
Efficiency	Low	High	High
Centralized	No	Partial	Yes
Consensus process	Permissionless	Permissioned	Permissioned

2.6.4 Blockchain platforms

After discussing the different consensus mechanisms and modes of operation, the next task is to examine the different blockchain platforms. These platforms use different consensus protocols and modes of operation to achieve desired performance characteristics.

Ethereum

In 2013, Vitalik Buterin published a whitepaper outlining a new type of blockchain platform called Ethereum. Ethereum launched in 2015 powered by its cryptocurrency Ether which is currently the 2nd most popular valuable cryptocurrency in the world behind blockchain (accurate as of May 2019 according to CoinMarketCap (2019)).

The key advancement that Ethereum provides over other platforms, such as Bitcoin, is that the platform allows for transactions to have a programmable nature. This allows for the creation of decentralized applications on the blockchain network that govern the terms and execution of transactions. Ethereum is a blockchain with a built-in Turing-complete programming language, allowing anyone to write smart contracts and decentralized applications where they can create their own arbitrary rules for ownership, transaction formats and state transition functions (Buterin, 2013).

With regards to accounts and transactions on the blockchain, there are three important differences that the Ethereum Blockchain apart from Bitcoin at the time (Buterin, 2013). These differences are:

- Accounts and messages can be created both by an external entity (person owned account) or by a programmed self-executing contract. This is opposed to Bitcoin where they can only be created and controlled by external entities.
- There is an explicit option for Ethereum messages to contain data in addition to currency. In the Bitcoin Blockchain transactions can only involve cryptocurrency.
- If the recipient of an Ethereum message (transaction) is a contract account, the contract has the ability to return a response which means that Ethereum transactions encompasses the concept of functions.

The implication of these three differences means that Ethereum has economic, business and industrial applications beyond that of simple peer to peer cash transactions (Yli-Huumo, et al., 2016). Ethereum has accounts that are either:

- Controlled by external entities by the use of private keys as in blockchain. These accounts have no code and sends messages by creating and signing a transaction.
- Controlled by programmed contracts that execute and transmit messages containing transactions or data based on predetermined conditions. These accounts activate once a message is received and then runs the code to determine the required actions.. This allows it to read and write to internal storage and create and send messages to other coded accounts.

A transaction in Ethereum terms refers to a signed data package that stores a message to be sent from an account and contains: the recipient of the message, a signature identifying the sender, the amount of ether and data to be sent and two values namely Gasprice and Startgas which refer to the transaction fee and amount of computational steps miners exert on the transaction. In Ethereum, coded contracts have the same power and functionality as those owned by external entities. According to Buterin (2013), Ethereum is an upgraded version of the traditional blockchain and offers features such as: on blockchain escrow, withdraw limits, financial contracts, decentralized apps data storage and a highly generalized programming language. It has laid the foundation for a blockchain platform that can be adopted by businesses and industries for many needs. Since its release, it has been used for many different industry projects. Further advancements and alterations are constantly being made to improve performance and features to suit individual needs. The fact that it is open source, can be both private or public makes it flexible and useful for many projects.

Hyperledger

The Hyperledger project was founded in 2016 by the Linux Foundation to advance cross industry blockchain technologies. Instead of deciding on a single blockchain standard, Hyperledger is a type of umbrella project that houses different blockchain approaches developed through a community process. They are supported by big companies such as IBM, Intel, SAP and others, in order to advance the development and use of blockchain and DLT's in industry.

According to the Hyperledger foundation, Hyperledger is an open source collaborative effort to advance cross industry blockchain technologies hosted by the Linux Foundation. It has a global collaboration spanning finance, banking, IoT, healthcare, manufacturing, technology, supply chains and more (Hyperledger, 2018). The goal of Hyperledger is to have a community of open source teams that develops blockchain infrastructures for business and enterprise. Contrast to other platforms such as Ethereum, Hyperledger makes use of a more modular approach. They have different frameworks that are basically different types of blockchain solutions suitable for different approaches.

The philosophy that started Hyperledger was that it became evident to companies that they could achieve more when working together as opposed to working separately. They pooled resources and developed a cross platform open source solution that is adaptable to different use cases. According to the Hyperledger white paper, the benefits of open source are:

- Competitive features and capabilities.
- No vendor lock-in, so customers can easily switch.
- High-quality solutions.
- The ability to customize and fix bugs, through access to source code.
- Lower total cost of ownership.

These advantages reduces risk, increases speed to market and helps get a competitive edge over others (Hyperledger, 2018).

Distributed ledgers can have vastly different requirements depending on the different use cases. For example in high trust, secure financial and legal applications, blocks can be shorter in order to allow for more rapid confirmation. In other cases, where there is little trust, a slower block processing ledger would add more security. Hyperledger embraces these differences by housing a full spectrum of solutions as shown in figure 2-15 and further described in table 2-23, adopted from (Hyperledger, 2018). Each of these projects are:

- Modular, containing similar building blocks that can be changed and adapted.
- Highly secure, embracing security by design.
- Interoperable: In the future, data exchange between blockchains is key to forming more powerful networks.
- Cryptocurrency agnostic, meaning they will not administer their own cryptocurrency. Their design philosophy however does include crypto and tokenization capabilities.
- Complete with API's. Hyperledger projects provide rich and easy to use API's that support interoperability with other IT systems already in use by companies in industry.

Table 2-23 Description of current Hyperledger projects

Hyperledger Project	Overview
Burrow	A modular blockchain client with a permissioned smart contract interpreter developed in part to the speciation's of the Ethereum Virtual Machine (EVM).
Fabric	A platform for building distributed ledger solutions with a modular architecture that delivers a high degree of confidentiality, flexibility, resiliency, and scalability. This enables solutions developed with Fabric to be adapted for any industry.
Indy	A distributed ledger that provides tools, libraries, and reusable components purpose-built for decentralized identity.

Iroha	A blockchain framework designed to be simple and easy to incorporate into enterprise infrastructure projects.
Sawtooth	A modular platform for building, deploying, and running distributed ledgers. Sawtooth features a new type of consensus, proof of elapsed time (PoET) which consumes far fewer resources than proof of work (PoW).

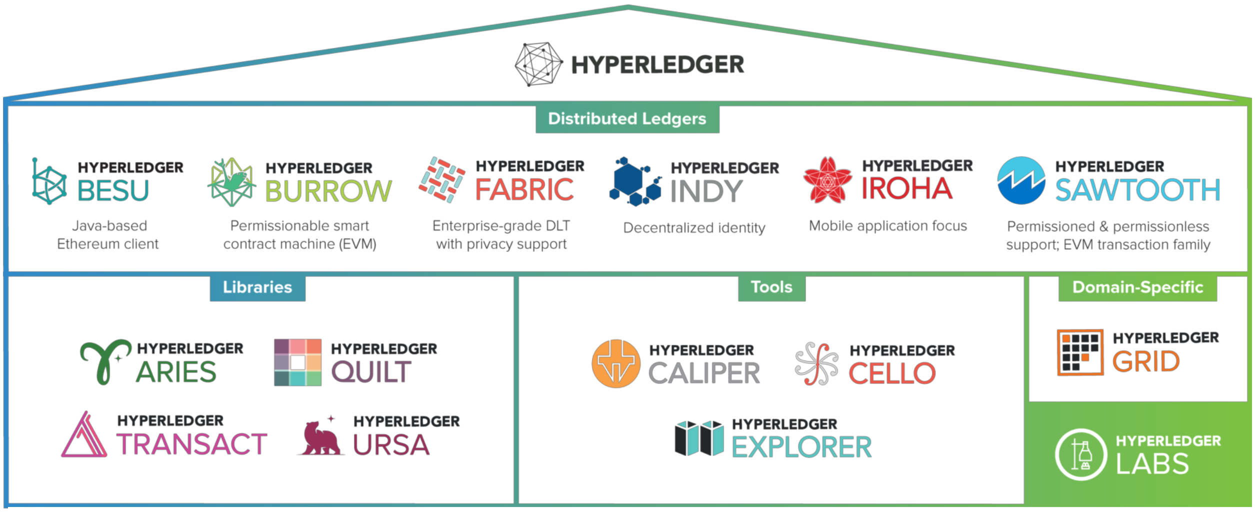


Figure 2-15 The Hyperledger ecosystem

In supply chain case studies involving tracking and tracing, it was evident that there are two preferred platforms namely Hyperledger Fabric and Sawtooth. An elaboration on the two platforms are provided below.

Hyperledger Fabric

Hyperledger fabric is one of the blockchains within Hyperledger. It is a private and permissioned blockchain where members enrol through a trusted membership service provider (MSP). Ledger data can be stored in multiple formats, consensus mechanisms can be swopped in and out and different MSP's are supported. Privacy is one of the top concern for fabric. Channels can also be created allowing groups of participants to create a separate ledger of transactions. This is important in the case where networks contain participants that might be competitors and would not want every transaction they make known to other members. Channels allow for participants to have unique copies of their parts of the ledger for a specific channel whilst still maintaining the benefits of the blockchain to all involved. It also supports the creation of smart contracts.

The fabric subledger system has two components, a world state and the transaction log. The world state describes the state of the ledger at any given point in time. The transaction log records all transactions, which resulted in the current value of the world state. It is the updated history for the world state. Concerning consensus, transactions must be written to the network in the order in which they occur even if it's between different sets of participants. The best method to ensure security and consensus is still a hotly debated topic, fabric thus allows network participants to choose the desired consensus mechanism to suit the relationship needs.

Hyperledger Sawtooth

Hyperledger sawtooth is an enterprise blockchain platform for building safe distributed ledger applications and networks. According to its documentation, sawtooth simplifies blockchain development by separating the core blockchain system from its application domain (Hyperledger Sawtooth, 2017). This means that those designing a blockchain application can specify it in the language of their choice without needing to know the underlying workings of the system. This makes it faster and easier to understand and deploy in use cases. As with Fabric, Sawtooth is highly modular allowing for users to choose transaction rules, consensus mechanisms and permissioning best suited to the individual use case. Currently supported consensus mechanisms include Proof-of-Elapsed-Time (POET) and dev-mode which is a simplified consensus algorithm. Sawtooth allows different type of consensus mechanisms to be used on the same blockchain and can be changed on a running blockchain with a transaction.

Sawtooth is built to work as a private blockchain where the details of its permissioning can be customized. However as clusters of nodes can be deployed with separate permissioning, there is no centralized service that can compromise security. Whilst most blockchains use serial execution, Sawtooth allows for transactions to be executed in parallel for increased performance whilst at the same time preventing security risks such as double spending.

2.6.4.1 Quorum

Quorum is a slightly modified version of the Ethereum blockchain that is more enterprise focused. It is ideal for applications requiring high speed and high throughput processing of private transactions within a group of permissioned and known participants. It is very similar to Ethereum but with a few improvements that addresses privacy and performance. Originally developed for the financial industry, it has found many use cases including those in supply chain. According to its GitHub documentation (JPMorganChase, 2018) its primary features are:

- Transaction/contract privacy and transparency
- Multiple voting-based consensus mechanisms
- Network/Peer permissions management
- Higher performance and throughput

In the Ethereum and Bitcoin blockchain there is no complete guarantee over the security of data due to the fact that transactions are open and visible. This has hindered many possible use cases from adopting the technology over security fears. The way Quorum differs from Ethereum is that it is a permissioned network meaning that only validated members can be part of it. Peer permissioning is done through smart contracts making sure only known parties can join the network. Quorum supports the use of both public and private transactions. Public transactions are executed in the standard Ethereum way. Private transactions and private contracts are done through public/private state separation and utilises peer to peer encrypted message exchanges for direct transfer of private data to network participants. As there is no need for POW/POS mechanisms, Quorum can make use of multiple consensus mechanisms namely:

- Raft-based consensus, a consensus model for faster block times, transaction finality and on demand block creation.
- Istanbul BFT (Byzantine Fault Tolerance) Consensus, a PBFT-inspired consensus algorithm with transaction finality.

Quorum's consensus mechanisms are more suited to consortium chains consisting of several different companies (JPMorganChase, 2019). Transactions in a consortium network are only visible to those involved. At the same time all nodes on the network still participates to enhance security. The higher performance of Quorum means that it can process over 100 transactions per second, much higher than that of bitcoin and Ethereum.

2.6.5 Comparison of Blockchain platforms

In order to compare the different platforms, a similar approach will be taken as done in Valenta & Sandner (2017) and Macdonald, et al., (2017). In these papers different amongst others Ethereum and Hyperledger is compared on a variety of different criteria. In this section, that comparison will be done with the inclusion of Quorum.

2.6.5.1 General platform comparison

After consulting the whitepapers and documentation of Ethereum, Hyperledger and Quorum it becomes evident that each has clear differences with regards to their visions and philosophies towards applications. Table 2-24 provides a summary of these differences. The Hyperledger platforms offer a more modular and extendable architecture that can be deployed to various use cases from asset management, banking and healthcare over to supply chains. In contrast to Hyperledger, Ethereum is not modular but it is a more generic platform that can be adapted to suite any kinds of transactions and applications (Valenta & Sandner, 2017). Quorum is an example of an Ethereum platform that was adapted to add and enhance certain features required in finance use cases.

Hyperledger and Ethereum platforms are both flexible but in different ways. Ethereum is a powerful generic smart contract platform that can be used for almost any application. However, its permissionless (public) mode of operation and full transparency comes at a cost of performance scalability and privacy (Valenta & Sandner, 2017). Quorum solves this issue by making private transactions possible through a permissioned mode of operation. Private blockchains allow larger files to be stored such as photos and documents. In a public blockchain such as Ethereum this will be inefficient and expensive. Currently, Ethereum uses a resource intensive proof of work consensus mechanism which hinders scalability. There are however plans to switch over to proof of stake to improve scalability (Macdonald, et al., 2017).

Hyperledger Sawtooth on the other hand is a highly modular and versatile blockchain platform. The main limitation however is that its PoET consensus mechanism has not yet been fully implemented and is not as secure as required (Macdonald, et al., 2017). A major highlight of the system is that it includes two consensus mechanisms, each of which is intended for use in different situations due to their different performance characteristics and trade-offs. Its extensible transaction types also opens up more possibilities in terms of what that platform can be used for. In comparison with Ethereum, Ethereum does not have the modularity or extensions, but unlike others, its flexibility has already been proven by the hundreds of different applications and case studies that have already been completed using Ethereum.

Table 2-24 Comparison of relevant blockchain platforms

Characteristic	Platform				
	Ethereum Based		Hyperledger		Bitcoin based
	Ethereum	Quorum	Fabric	Sawtooth	Bitcoin
Description	Generic blockchain platform	Privacy and performance enhanced Ethereum blockchain	Modular blockchain platform	Highly modular and versatile blockchain platform	Decentralized peer to peer cryptocurrency network
Mode of operation	Permissionless Public	Permissioned private/hybrid	Permissioned private	Private	Permissionless public
Consensus	Proof-of-work based mining	Raft-Based, Istanbul BFT, voting based	Multiple approaches possible	Multiple approaches possible	Proof-of-work
Smart contracts	Smart-contract code(eg. solidarity)	Private smart contracts	Smart-contract code(eg. Java, Go)	Smart contract abstraction	None
Currency	Ether or tokens via smart contract	N/A	None	None	Bitcoin

2.6.6 Blockchain architectures

With the deployment of blockchain comes the question of how to best organize its architecture to navigate the different potential users, parties and transactions. There are different configurations of blockchain architectures which are suited to different environments. The different architectures, found to be relevant to supply chain and IT were presented and presented and evaluated in *O'Leary* (2017) and *Accenture* (2018). The subheadings below aims to provide an overview of the different architectures used in practise.

The 'classic, open and public' blockchain architecture

This architecture is representative of a public blockchain, (such as Bitcoin), the first implementation of the technology. In this environment, all transactions occur openly on the public ledger, shown in figure 2-17. This peer to peer system has numerous advantages. Firstly, the open public ledger gives participants a clear understanding about the market and asset of interest, in this case bitcoin. Secondly, the visibility guarantees assurance that the transactions are validated according to the system rules (consensus is achieved). Thirdly it generates incentive for all users to care about each transaction as it affects the market for the users own bitcoins.

However, this architecture does have some downsides when it comes to certain applications, such as in the supply chain where multiple parties are involved. A possible threat is presented to competitors as transactions are visible and could be used to gather business insights of other competing parties. Another factor is scalability. The public blockchain is not efficient enough to capture all the information involved in a business centric transaction. In the traditional Bitcoin blockchain, transactions take 10 mins to verify and 1 block has a size limit of 1mb (Macdonald, et al., 2017). Energy consumption due to computation power is also a major drawback. The information captured by such a blockchain would be minimal and would not meet each organizations total transaction and recording requirements (O'Leary, 2017).

Further, an open architecture is prone to fraudulent and criminal activity as there is no barrier for entry preventing actors with malicious intent from taking part in the network activity. The integrity of the blockchain is not the issue, it is rather other malicious activities that may foster when the wrong actors have access to certain information regarding transactions of individuals or companies. *Popper & Lohr* (2017) have noted that it is very unlikely that companies in accounting and supply chain environments will make use of an open public blockchain architecture. Rather it is expected that a private blockchain is more suitable of which there are many different configurations.

Single company configuration: Granting auditor or regulatory access

In this configuration, a company makes use of a single private blockchain to capture each of the supply chain transactions, shown in figure 2-16. This is as opposed to a private consortium or public blockchain. *O'Leary* (2017) describes this approach as a 'single source of truth'. In this setting no-one has access to the information on the blockchain. Only the company grant its auditors or regulators access the information. This sort of system draws parallels to ERP systems which captures all the information about processes and transactions and allowing regulators to access that info to gain insights into the company.

Each transaction is written into the blockchain as a hash string which the auditor or regulator can then later search to determine if this transactions has been changed or not. Even though this method has the advantage of maintaining the original record, it does not guarantee the quality of the entry as there is only 1 party involved. There is no public consensus to ensure the correctness of the transaction entry. Trust is not generated by a network of peers as there is only the firm involved.

This system is similar to existing IT and transaction processing systems in companies today. There is thus no need to adopt a similar system based on blockchain. The economic benefit of blockchain is the fact that it has a network of peers that insures trust, a principle this architecture deviates from.

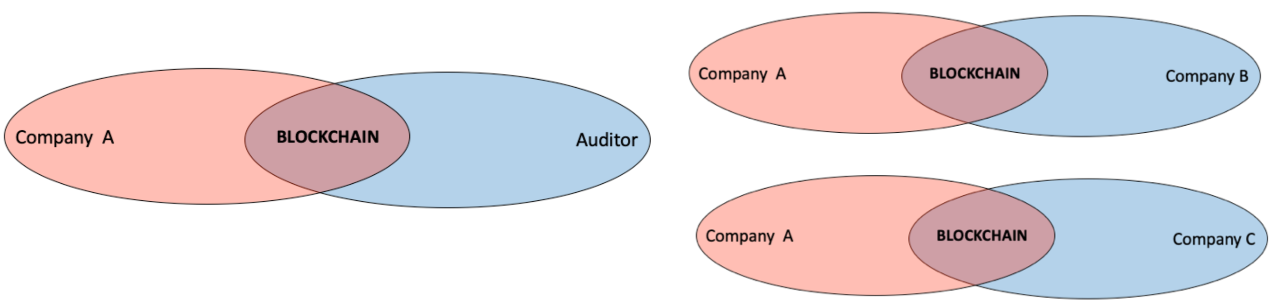


Figure 2-16 Single company configuration (left) and pairwise (right)

Pairwise corporate use of Blockchains

In this approach, there would be two companies making use of the same private blockchain, figure 2-16. This architecture will be helpful if the two firms are working closely together or one company is in close collaboration with another. A shared blockchain between these two parties would provide transactional clarity and remove any friction with regards to visibility and information sharing. This approach however, as with the previous architecture, is not a consensus based approach due to the limited number of parties involved in validating transactions (namely two). Additionally, systems would have to be developed in order to link the blockchain to each company's internal IT or ERP system.

Multiple consortium companies all using the same blockchain

The fourth approach, proposed by O'Leary (2017) and shown in figure 2-17, is one where multiple independent companies form part of a private consortium type blockchain.

- This blockchain would be used to, for example, capture a particular type of transaction that relates to the exchanges by these companies (such as a product in a supply chain).
- These companies can have a standard process of doing business.
- This can also occur when there is a large company in the industry with power that wants to assure that the firms it is dealing with are trustworthy and transactions visible, thus obliging them to be part of the blockchain network.
- There could be an organization at the centre of a large set of transactions such as a shipping or supply chain firm. They want better control and visibility over transactions.

To control privacy and business intelligence of the individual companies involved, the platform can offer different views to each party. In this way some parties can be restricted from viewing sensitive information from a potential competitor whilst still working on the same blockchain network. Each company can still make use of its own internal IT and accounting system to capture, store and process information that is beyond the blockchain. Later that information can be integrated with the blockchain platform and be publicly shared.

When comparing this private model to an open public blockchain there are apparent differentness. In bitcoin, the large network of participants and the consensus mechanism is used to verify information/transactions and provide trust. Cloud based. In the private consortium model there are however fewer members. These members will also not all be equal as represented by the difference in market power between the companies. In such a blockchain system, the various participants would also have to be known. The way in which consensus and transaction validation would occur in such a scenario is not currently clear according O'Leary (2017). The author goes on to make the point that, '*if an architecture exists that lacks anonymity, is centrally controlled, cloud based and not peer to peer, then is the resulting system still a blockchain*'?

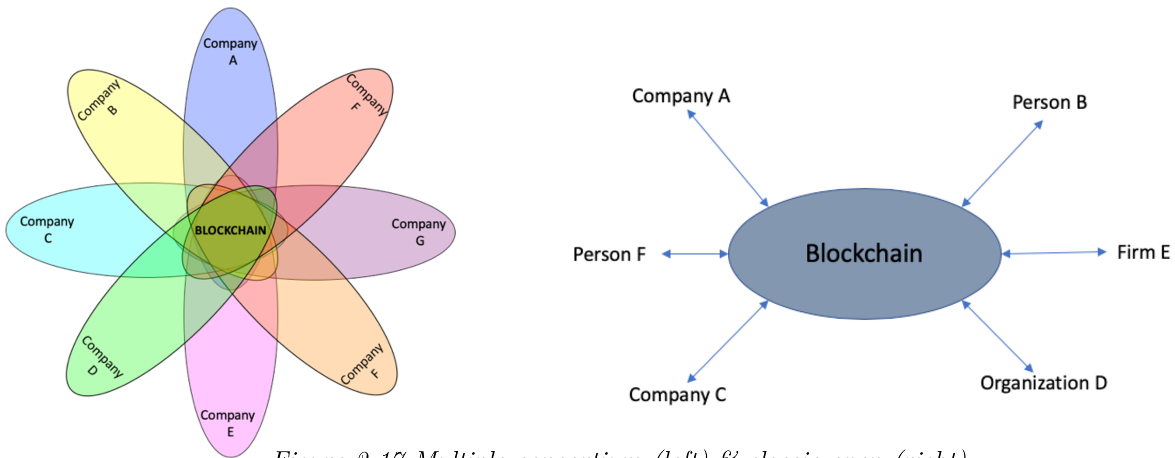


Figure 2-17 Multiple consortium (left) & classic open (right)

Central Hub and Spoke

Typical of a market centric or market leader model, in this approach a company would lead in the efforts of designing implementing and operating a supply chain blockchain program. They would typically get the rest of the supply chain partners on board to adopt blockchain and be part of the network. This example is typically seen in blockchain pilot programmes in the supply chain that is led by the dominating company. A illustration is shown in figure 2-18.

Consortium of peers

In this model there are many different entities (such as companies, regulators, governments, producers, suppliers etc.) that all agree or have interest to build and operate a blockchain supply chain system. Each of the different participants would typically have their own incentives for joining the network. This model is more complex in terms of governance and adoption when compared to the hub and spoke model yet outcomes can be more transformational as it considers a wider ecosystem of stakeholders vertically and horizontally. A illustration is shown in figure 2-18.

Platform install base converted to network

In this approach, organizations are already communicating with each other using data and information transactions and would benefit from using a blockchain to connect. The addition of adding the blockchain on top of existing systems would increase efficiency and reduce the need to validate information and reconsolidate data between the parties.

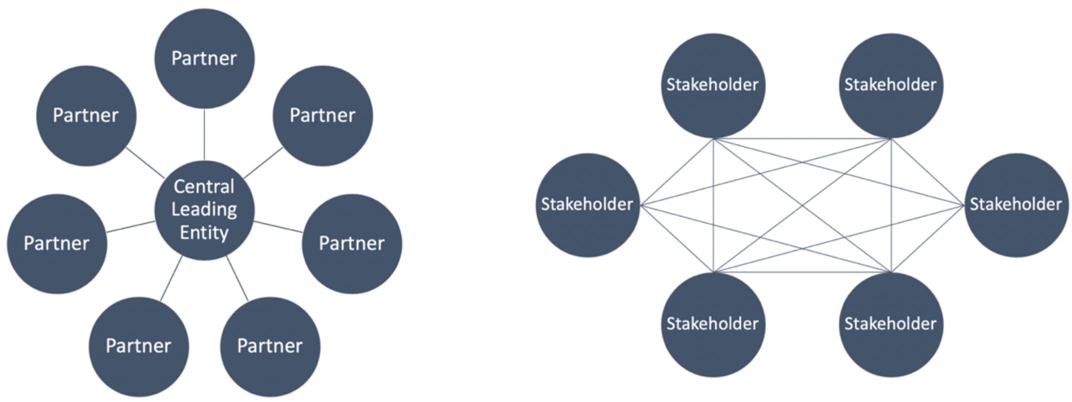


Figure 2-18 Hub and spoke (left) & peer consortium (right)

2.7 Literature summary and conclusion

2.7.1 Key insights

The literature review obtained an insight into the use of blockchain in the supply chain, and resulted in the following key findings:

- Current supply chains rely on a mixture of digital and paper-based processes held up in ‘silos’. This hinders effective information sharing, resulting in a lack of trust and transparency.
- Changing consumer demands, market climates and issues such as influx of counterfeit goods and food scandals, are driving supply chains to become more transparent.
- Supply chain digitalization involves the creation of supply chain ecosystems that are more flexible, responsive and transparent.
- Tracking and tracing is one of the key elements of supply chain digitalization as it aids in facilitating transparency. Current methods, however, are fragmented, slow and ineffective.
- Blockchain technology has the potential to enable end-to-end supply chain visibility, providing a secure method of tracking products in the supply chain, enabling trust and provenance.
- There is no formal definition for blockchain. Most definitions refer to a distributed ledger enabling data immutability, auditability and transparency where new transactions are grouped into blocks and added to a sequentially linked chain.
- There are many important technological aspects of blockchain such as: consensus mechanisms, blockchain platforms, blockchain architectures and modes of operation.
- There is no clear indication of which architecture is best suited to certain cases. A combination of different architectures are used to facilitate supply chain track and trace.
- Industry case studies focus on using blockchain to enable traceability, visibility, provenance and automation. They mainly use Ethereum and Hyperledger platforms with a mix of public and private ledgers, although most are private. Blockchain is used for food traceability, end-to-end visibility and ensuring provenance.

2.7.2 Key parts for further use

The findings from the case studies and the analysis of the various technological architectures are key parts that will be used in further parts of the study. These will be used to help determine the different decisions and requirements, relating to the technological and product aspects of blockchain in the supply chain.

2.7.3 Critical analysis and judgement

The overall notion of blockchain research is that, there is consensus on the fact that blockchain will contribute significantly towards the supply chain. This contribution will involve the enabling of end-to-end transparency. What is currently not clear, is how exactly this will be achieved.

To conduct this literature review, the current research on blockchain technology and its use in the supply chains had to be gathered. Online e-databases such as ACM, Scopus, Google Scholar, ScienceDirect, IEEE, Springer and SUN Library were used. SUN Library was found to be most effective as it performs searches across more than 280 different online databases (Stellenbosch University, 2019). Various combinations of search terms were used including, but not limited to:

- ‘blockchain’
- ‘blockchain tracing’
- ‘block + chain’
- ‘blockchain supply chain’
- ‘supply chain track and trace’
- ‘tracking and tracing’
- ‘blockchain digitalization’
- ‘supply chain digitalization
- ‘blockchain’ architecture’
- ‘blockchain track and trace’
- ‘blockchain framework’
- ‘blockchain application’

The searches found that there was a limited amount of research dealing specifically with blockchain in the supply chain. When the focus is made to include only peer reviewed journals, these results are even less. Thus, many of the facts and statements presented, came from research where the main focus was outside of the supply chain. As most of blockchains’ development, thus far, has occurred outside of formal academic environments, whitepapers, reports and use-case analysis were often the most valuable and up-to-date resources. There was no clarity found regarding the recommended design guidelines, principles, architectures, use cases or implementation methods. Overall, it was difficult to find high quality research on blockchain technology and its use in the supply chain.

This is supported by the statements made in the problem statement, which indicated that there are few academic studies dealing with the application of blockchain in the supply chain (Denner, et al., 2018; Yli-Huumo, et al., 2016; Nofer, et al., 2017; Gausdal, et al., 2018; Risius & Spohrer, 2017). In the following chapters, the results from the literature analysis will be used, in combination with an evaluation on blockchain frameworks, in order to identify and extract the important guidelines and requirements that are needed for blockchain in the supply chain. This procedure will aim to fill the gap in the literature relating to the lack of application research and design guidelines.

Chapter 3 Design Reference Architecture Development

This chapter will cover the development of the design reference architecture. It begins with a background on reference architectures, highlighting some popular architectures in existence, followed by the methodology used to develop the architecture used in this study. After this, the various blockchain requirements are gathered from literature and analysed. Finally, the process of designing the DRA is presented. It will explain how the different requirements were characterized and used as a basis to design the architecture. This outline is highlighted in figure 3-1.

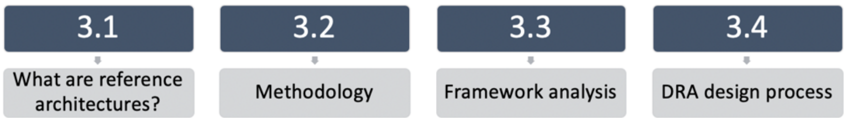


Figure 3-1 Chapter 3 overview

3.1 Design Reference Architectures

3.1.1 What are reference architectures?

There are many different types of reference architectures in use. This section aims at exploring these reference architectures and formulating a description for a design reference architecture. The different definitions explored were gathered from the engineering, business and information technology fields as that is what the scope of this thesis involves.

An architecture can be defined as the fundamental organisation of a system embodied in its components, their relationships to each other and to the environment and the principles guiding its design and evolution (Verdouw, et al., 2018). Reference architectures are predefined models of recommended practices that are used as a frame of reference, and as such can improve the quality, speed and cost of the information modelling process (Verdouw, et al., 2010).

Other definitions state that it provides a methodology or set of practices and templates that are based on the generalization of a set of successful solutions for a particular category of solutions; They provide guidance on how to apply specific patterns and practices to solve particular problems. In that way, they serve as a reference for specific architectures that a company will implement (Giachetti, 2010). They are also described as generic architectures that can be used as the starting point to derive an enterprise architecture (Giachetti, 2010).

There are many different diverse definitions for enterprise reference architectures but they are often described as dynamic structures that encapsulates both technical, social, logical and dimensions of an enterprise. *Du Preez, et al.* (2015) defines enterprise reference architectures as a model or framework which describes the different activities that should be performed, tools/methods available and procedures to follow in an enterprise engineering endeavor. It serves to guide and support engineering teams on what to do when designing or redesigning an enterprise or system.

The design reference architecture is thus concerned with the design component of reference architectures. It represents different principles, guidelines and best practices that can be consulted in order to aid the design or development of information systems.

3.1.2 Design Reference Architectures versus Frameworks: Why a reference architecture?

The definitions for reference architectures and frameworks often intersect. They are both different tools, models or foundations of knowledge and principles that can be used to guide a specific process or endeavour. Frameworks give enterprise architects the tools they need to adequately describe and collect requirements without mandating any specific architecture type. Reference architectures go a step further by accelerating the process for a particular architecture type. It helps identify which architectural approaches will satisfy requirements and which minimally needed architectural artefacts are needed to meet the best practices. Although both frameworks and architects provide best practices, an architecture provides more of a methodology around it when compared to frameworks (Paradkar, 2018).

Research further motivates that reference architectures are more commonly used for, and better suited to, the design and re-design of information systems (such as a blockchain system) (Du Preez, et al., 2015). When compared to frameworks, they are more comprehensive and offer a higher level of detail. They describe the sections of the architecture in more detail as well as the interrelations between the different elements. Table 3-1 highlights the motivation for why a reference architecture was chosen over a framework or other tool.

Table 3-1 Motivation for the use of a reference architecture

Motivation for reference architecture
- Better suited towards the design and redesign of information systems.
- Are more comprehensive and detailed when compared to frameworks.
- Shows interrelation between different architecture elements.
- Proves a methodology around best practices and guidelines.

3.1.3 Examples of popular reference architectures

Zachman Framework for enterprise architecture

In 1987, John Zachman published the first version of the now famous framework for information systems architecture. The architecture acts as a comprehensive checklist to follow during business analysis or enterprise architecture design, even though its original intent is suited to the design of information architectures (Du Preez, et al., 2015). The framework consists of a matrix as shown in figure 3-2 (Zachman, 2008) that depicts six communication interrogatives (what, how, where, who, when and why) as columns, and six reification transformations (scope contexts, business concepts, system logic, technology physics, tool components, and operations instances) as rows (Gous, 2014).

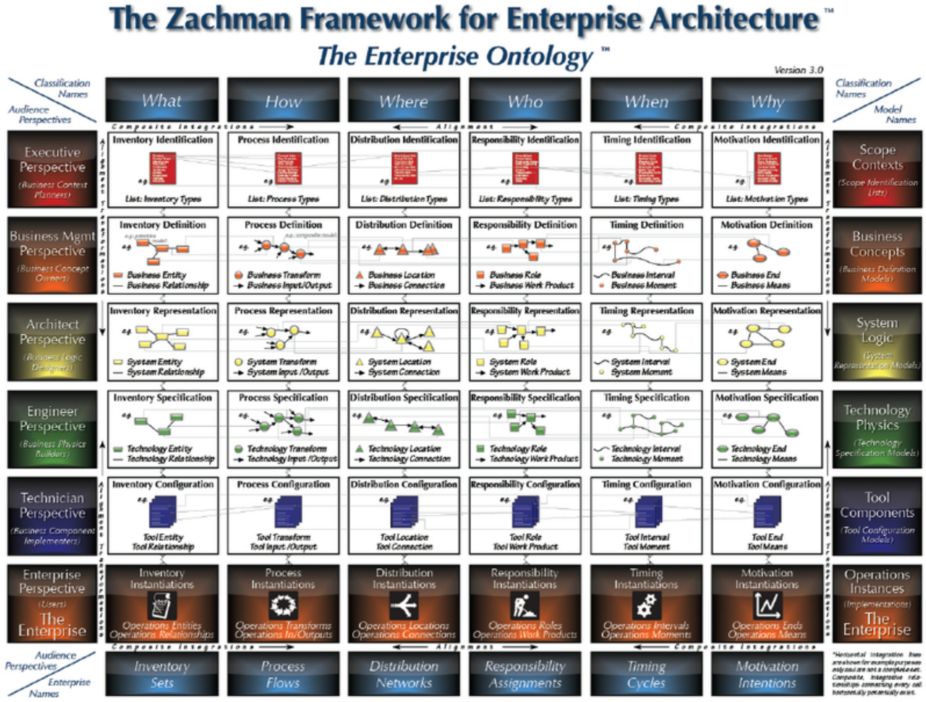


Figure 3-2 The Zachman reference architecture

PERA and Master plan

The Purdue Enterprise Reference Architecture was developed at Purdue University and serves to provide a life cycle model which demonstrates how to integrate enterprise systems, physical plant engineering and organizational development from enterprise concept to dissolution (Du Preez, et al., 2015). Basically, it describes the activities to be performed during the life cycle of an enterprise from initial conception until disposal. It views these life cycle stages from three different perspectives:

- Information system tasks
- Manufacturing tasks
- Human based (organizational) tasks

Even though it is focused on manufacturing, its principles can be applied generically across a diverse range of organizations. Figure 3-3 below shows the overall life cycle phases of the architecture.

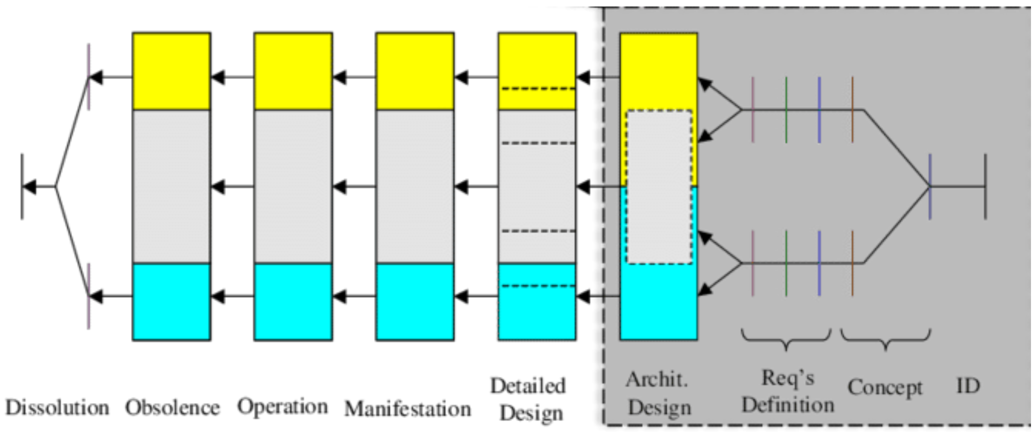


Figure 3-3 The PERA reference architecture

TOGAF Reference Architecture

TOGAF, or The Open Group Reference Architecture, is primarily an information technology (IT) architecture that aims to align IT with the business view. It strives to improve business efficiency by helping practitioners avoid being locked into proprietary methods, helping them utilize resources more efficiently and effectively, thus realizing a greater return on investment (TheOpenGroup, 2018). It describes four architectural views (Gous, 2014):

- Business architecture: processes the business uses to meet its goals and links strategy formulation to strategy implementation.
- Application architecture: describes how specific applications are designed and how they interact with each other.
- Data architecture: describes the enterprise's logical and physical data resources and how the data is managed.
- Technical architecture: describes the hardware and software infrastructure that supports the business processes, applications and their interactions.

The TOGAF architecture is made up of a modular structure which is divided into six sections namely the Introduction, Architecture Development Method (ADM), ADM guidelines and techniques, Architecture content framework, Enterprise Continuum & Tools and the Architecture Capability framework. Of the six, the TOGAF is best known for its ADM structure which describes a detailed approach to generate architecture descriptions and consists of ten phases. Figure 3-4 shows the TOGAF Architecture Development Method and the accompanying table 3-2 describes its various sections (TheOpenGroup, 2018; Gous, 2014).

Table 3-2 Description of the TOGAF architecture sections

	Phase	Description
	Preliminary	Defines the capabilities for doing architecture work, i.e. defining the 'where, what, why, who and how' we do architecture.
A.	Architecture Vision	Defines the scope of the architecture effort and the constraints that must be dealt with.
B.	Business Architecture	Defines the baseline and target business architectures, which is a prerequisite for architecture work in any other domain (data, application and technology).
C.	Information Systems Architectures	Defines the target data and/or application architectures that would support the target business architecture.
D.	Technology Architecture	Maps the data and/or application components (defined in Phase C) to a set of technology components, representing required software and hardware components.
E.	Opportunities and Solutions	Provides a logical grouping of IT activities into project work packages within the IT portfolio and other portfolios that are dependent upon IT.
F.	Migration Planning	Creates a viable implementation/migration plan in co-operation with the portfolio and project managers.
G.	Implementation Governance	Governs and manages the contract for implementing and deploying the solution(s).

H.	Architecture Change Management	Manages changes to the architecture in a consistent way.

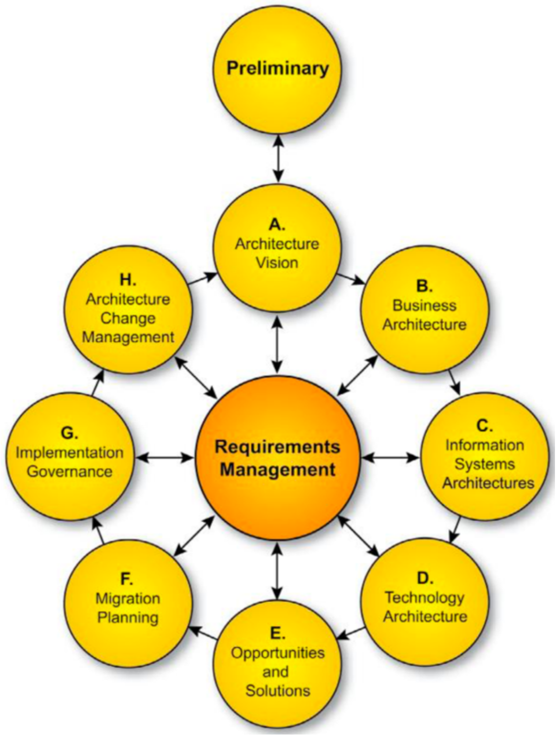


Figure 3-4 The TOGAF reference architecture

3.1.4 A Design Reference Architecture for Blockchain in the Supply Chain

The need for a design reference architecture to assist in the designing of blockchain based track and trace solutions has been clarified in the problem statement. Further, the benefits of an architecture approach over a framework has been described. After evaluating the problem statement, definitions and examples of reference architectures, the goal of the blockchain architecture is described as follows:

The main goal of the design reference architecture is to provide generic guidelines, principles, best practices and design considerations that will aid teams in the design of blockchain based tracking and tracing solutions in the supply chain. It should encapsulate both technical and social aspects and serve as a tool to enhance decision making, strategy and execution.

Figure 3-5 highlights the overall goal and purpose of the architecture. Although tracking and tracing using blockchain technology is predominantly focused on food supply chains, and that case studies and principles are mainly derived from that field, the architecture design guidelines will strive to remain generic in order to aid its applicability in a diverse range of supply chain cases.

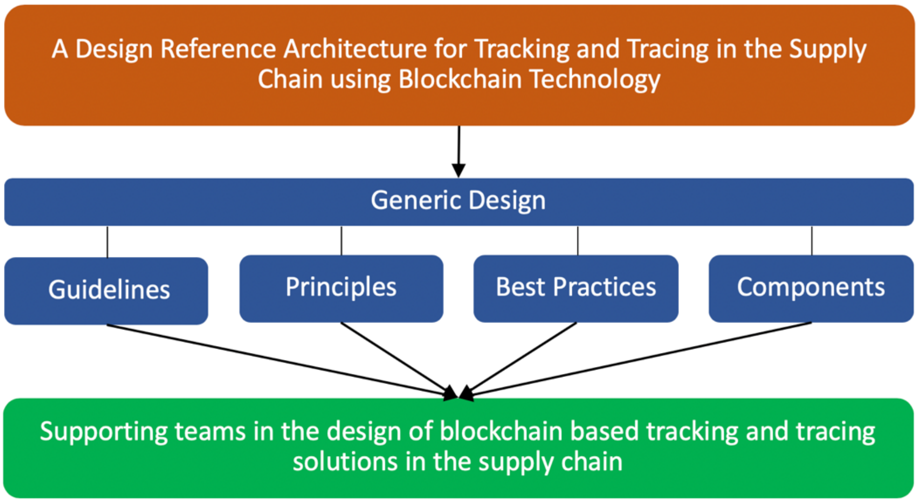


Figure 3-5 Goal and purpose of the design reference architectures

3.2 Methodology

The following section aims to describe and motivate the approach used in the development of the design reference architecture. In order to design the architecture, various blockchain supply chain requirements and guidelines have to be identified, which in turn will be used to construct the architecture. The original approach considered was to first define all the requirements relating to blockchain and supply chain track and trace through a literature, research and case study analysis. After those have been identified, they can be grouped according to relevance and used to construct the architecture, which in turn will be evaluated in a case study. There is very little research that deals with blockchain architectures for supply chain, however as blockchain is a type of information system, general information system architecture approaches can be used as a guideline towards this study.

3.2.1 Similar approaches and methodologies in research

The approach followed can be related to a general approach used in *Verdouw, et al.* (2018), where a reference architecture was constructed for an IoT based logistic information systems in agri-food supply chains. This case is, in some ways, a similar venture as the one undertaken in this masters project. Both deal with the design of a reference architecture for an information system using a new technology in the supply chain. In the case of Verdouw, et al. (2018), the reference architecture focuses on an IoT based solution whereas this project focuses on a blockchain based solution. In the case of the IoT reference architecture, the research was conducted in 3 stages showcased in the figure below.

Figure 3-6 Methodology used in Verdouw, et al. (2018)

The first step, done by the researchers, was to analyse the various requirements and characteristics of the supply chain from research. The defined functional and non-functional characteristics were then aggregated into an initial list and classified into different categories according to their relation. The second step was to design the reference architecture for an IoT based logistics information system in the agri-supply chain. The reference architecture was abstracted from case studies and a generic architecture was used as a theoretical basis. Common building blocks were identified and incorporated into the reference architecture. The third step was to apply the architecture to the agri-supply chain case study in order to determine if it can represent the challenges presented. It was also verified to what extent the reference architecture meets defined requirements. This was done by checking which architectural components address each of the requirement.

3.2.2 Methodology Used

This design methodology used in *Verdouw, et al.* (2018) shares some similarities with the one used in this thesis. They both deal with the design of a reference architecture involving an IT information system for supply chain applications. However as this study focuses on blockchain technology the design of the architecture will be different.

To construct the design reference architecture, the first step is to gatherer the different requirements, principles and best practices from research and case studies. Various blockchain design, feasibility and application frameworks were gathered along with track and trace case studies and other notable papers. From here, the different guidelines can be extracted and grouped together according to relevance. This will form the bases of the reference architecture design. After the architecture has been designed and populated with the different guidelines and principles, it needs to be evaluated. A case study in the FMCG food supply chain that involves the tracking and tracing of specific food using blockchain technology was chosen to be used in the validation of the architecture. A second validation was done through semi-structured interviews experts in industry. The process is displayed in figure 3-7 and will be described in more detail in the following sections.

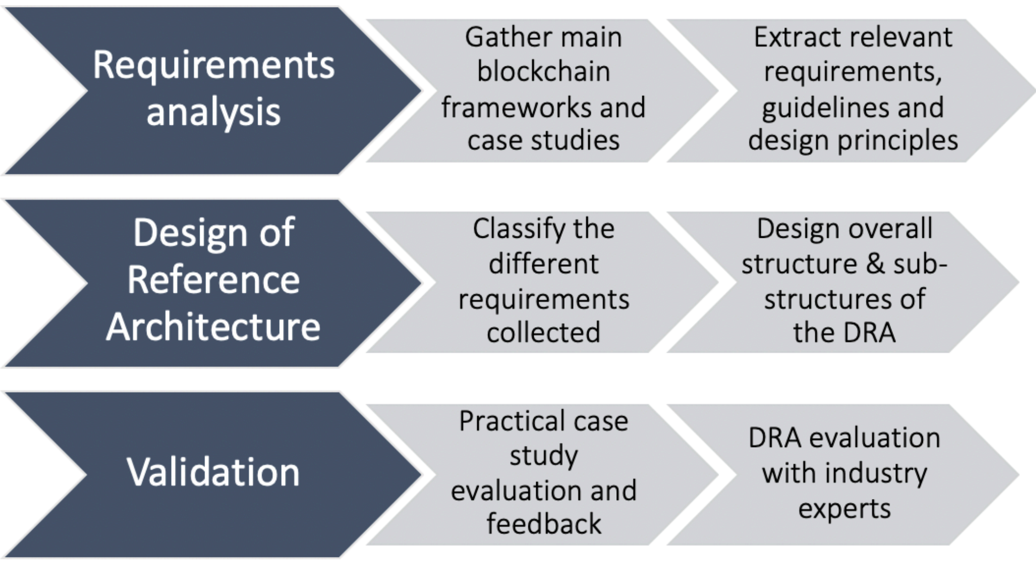


Figure 3-7 Overview of the methodology used in the DRA design

3.2.3 Requirements analysis

In the requirements analysis, the goal is to identify the various requirements, guidelines, best practices and design elements that relate to blockchains use in the supply chain. Figure 3-8 illustrates this research process. Currently, there was no comprehensive summary or collection of data identified, surrounding blockchain in the supply chain. This data had to be extracted from research dealing with the different aspects of blockchain in the supply chain. It was found that existing blockchain frameworks are the best sources to help identify the these various requirements. Frameworks present a collection of research and knowledge on current findings regarding specific topics of blockchains application. For example, there are frameworks for determining blockchain applicability in the supply chain, and others that deal with blockchain business decisions. They contain a summary of the current level of knowledge and research in that specific topic. These frameworks are, however, limited to a only a specific aspect of blockchain, a limitation which this study aims to expand with the design reference architecture.

In order to gather the main sources, online databases including ACM, Scopus, Google scholar, ScienceDirect and SUN Library were consulted. SUN library was particularly effective as it does searches across over 280 different online libraries and e-databases (Stellenbosch University, 2019). Search terms such as 'Blockchain', 'Block chain', 'Blockchain Framework', 'Blockchain Reference Architecture', 'Blockchain Design Framework', 'Blockchain Supply Chain', 'Blockchain tracking and tracing', 'Blockchain Architecture' and many variations were used to gather data. Once the research was done, the relevant blockchain frameworks were identified, shown in figure 3-8.

Apart from the frameworks, case studies involving blockchain tracking and tracing and other sources on blockchains technological architectures, provided many design guidelines and considerations that will be used. They were identified and discussed in the literature review chapter. There are a few well known case studies such as those from Walmart and IBM and a few other lesser known cases that was discussed.

The next step was to gather the relevant guidelines, principles, best practices and design considerations from these different blockchain frameworks and case studies. Once they were extracted, they were grouped according to their relevance. For example, some guidelines referred to the blockchain technology itself whilst others referred to business or supply chain aspects surrounding blockchain. The aim was to gather different principles relating to the technology side as well as the business, supply chain, social, product and strategy side. This was to make sure that the architecture is comprehensive and focuses on all issues surrounding blockchains deployment in the supply chain, not just the technology itself. Once they have been extracted, they can be classified into different groups.

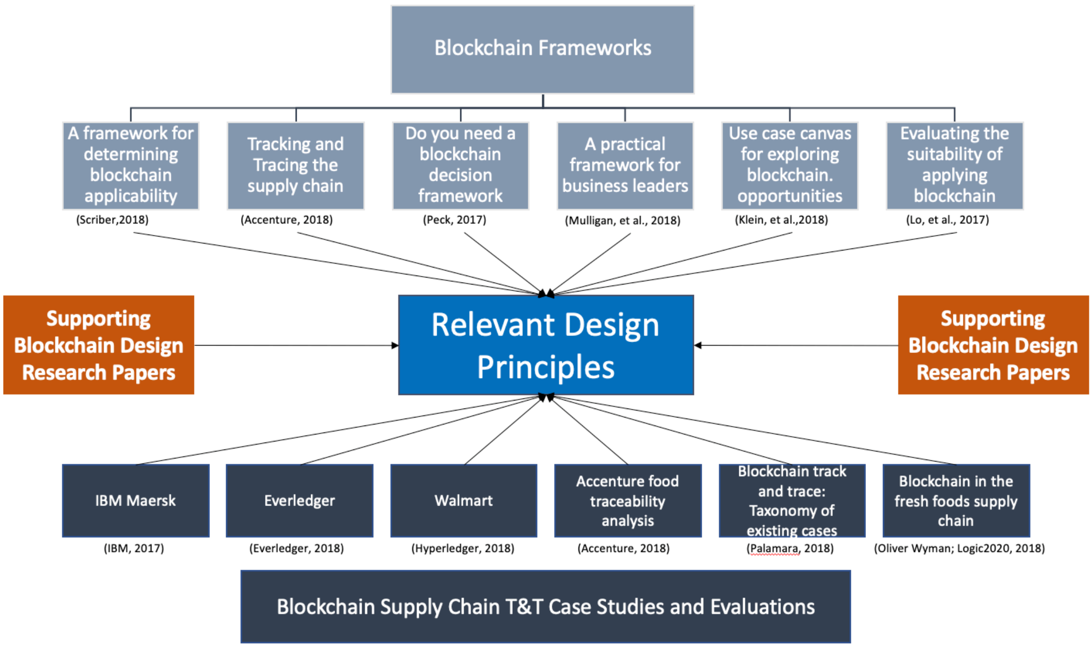


Figure 3-8 Overview of requirement extraction process

Overall, there is very little development in the blockchain supply chain. Most case studies are still pilot projects and have not been deployed full scale. From the research perspective, there are not many studies or frameworks that deal with blockchain technology let alone its application to supply chain tracking and tracing. Regardless, the goal of this analysis was to gather the latest existing blockchain research in order to extract the most relevant design guidelines for blockchain in the supply chain.

3.2.4 Design of Reference Architecture

After the various guidelines, requirements and principles have been extracted from the frameworks they can be classified into different groups according to their similarities. This helps to identify the various aspects of the architecture design. The common themes from the different groups of guidelines help to influence the overall structure of the architecture.

Existing architectures were used as a basic guideline on reference architecture design, most notably the TOGAF architecture. The approach this architecture used was to divide the overall structure into sub-architecture elements that groups requirements accordingly. TOGAF makes use of sub architectures that focus specifically aspects such as:

- The overall vision
- Business aspects
- Information systems
- Technology
- Implementation

These different sub-elements will be used as a relative guide in the design of the blockchain design reference architecture.

3.2.5 Validation

The final stage is the validation of the design reference architecture created. The validation will consist of semi structured interviews with industry experts in blockchain and supply chain. A practical case study application will also be done in order to test the real world applicability of the architecture. The main criteria along which the reference architecture is tested is:

- The validity of the content (are there enough elements included in the architecture).
- Applicability and use (is it easy to use and suited to the intended application).
- Practicality (will it be useful in practise).

This evaluation will be applied to the overall architecture as well as each individual sub-architecture section. The results will be generated through an interview process where the experts would have had time to evaluate the architecture and give their responses and recommendations guided by the criteria listed above. After evaluating the case study, recommendations will be generated along with a concept design which will be evaluated by the experts in charge of implementing the blockchain case study. The expert or team involved will review the recommendations and provide feedback. The overall process is shown in figure 3-9. Through these two validation processes, the usefulness and real world practicality of the architecture can be demonstrated.

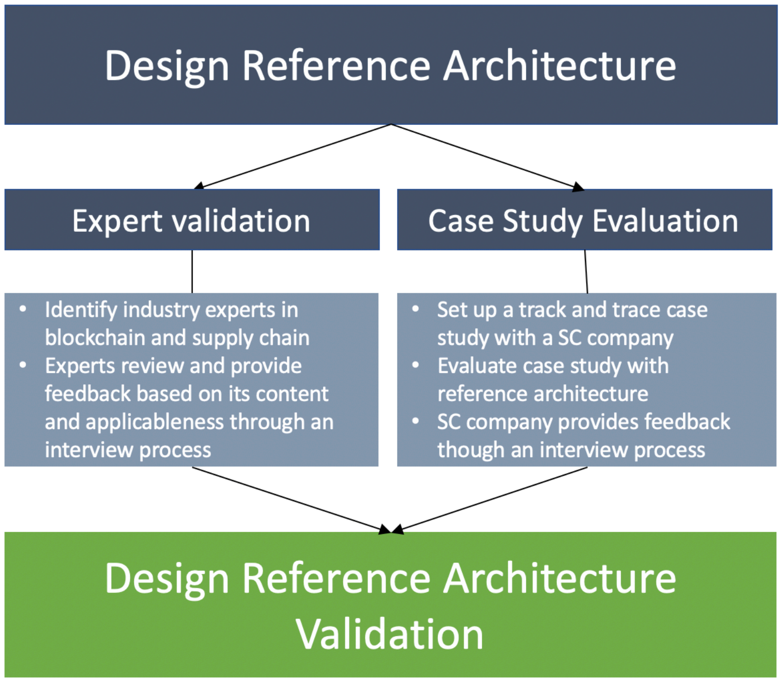


Figure 3-9 Overview of the DRA validation process

3.3 Framework analysis

At this point, a background has been given on reference architectures and a methodology has been formulated as to how to approach the design of a blockchain reference architecture for the supply chain. It was clarified that the next step is to identify the various requirements for blockchain in the supply chain by evaluating the relevant frameworks. This section will present and discuss the frameworks identified in figure 3-8. A brief summary of the framework will be given after which the relevant requirements will be extracted. The significance and details of each requirements or guideline will be explained.

3.3.1 A framework for determining blockchain applicability

This framework developed by *Scriber* (2018) and published in the *IEEE Software Journal* provides a basis for project leaders, engineers, investors and system architects to evaluate blockchain suitability for a given application. The framework was compiled by evaluating 23 different blockchain implementation projects and using the findings to develop questions that either leads towards or away from its suitability for implementation. These questions were then codified to create the framework. The evaluation also led to the discovery of 10 different '*blockchain or architectural characteristics'* that help determine blockchains appropriateness for applications. The framework goes into depth with each of these characteristics and can be consulted for a more in depth review.

In table 3-3, a summation of the framework is provided, adapted from Scriber (2018). It lists the different characteristics, gives a short description and highlights the key questions asked for each case. The answers to the questions give an indication for, or against the use of blockchain in the given problem space.

Table 3-3 Summation of the important framework characteristics

Characteristic	Description	Key Questions
Immutability	Achieved through cryptographic encryption and consensus algorithms, records cannot be changed once uploaded.	Does the system need a historical record of data that cannot be changed/will not need the ability to update or delete stored data?
Visibility & transparency	In blockchain, all network participants can see all transactions on the chain.	Does the architecture require transparency between actors?
Trust	Blockchains can remove the need for an ecosystem to trust a 3rd party, a key ability for certain applications.	Does the ecosystem currently lack trust between participants? Do participants ask the question, "*how can I verify that a certain event happened?*"
Identity	Applications will benefit where identify is strongly related to the signing of a transaction.	Is identify strongly coupled to the signing of a transaction? Must network participant be mapped to transactions?
Distribution	Distribution provides four key advantages desirable for blockchain architectures. 1.) Reliability, if one node fails you have others to continue support for the ecosystem. 2.) The more participants and distribution complexity, the more secure the blockchain network. 3.) System integrity and ability to verify data. 4.) Byzantine fault tolerance, the tolerance of bad actors in the system without compromising the system integrity.	Can the implementation manage and afford distribution of nodes and participants? How many stakeholders are there in the ecosystem and can each stakeholder run nodes? Does the scale of distribution provide enough participants to achieve security, reliability and achieve its goals?
Workflow	Adding blockchain to a traditional centralized system creates architectural hurdles. Workflow must be evaluated for an appropriate fit.	Would the addition of a distributed ledger simplify workflow?
Transactions	The blockchain is a visible ledger of transactions. If a system is not transaction based, conversion to blockchain would be difficult.	Does the system follow a transactional model, or is data transactional?
Historical record	The fact that the ledger will have a permanent record of data indefinitely needs to be taken into consideration.	Is the project ready to assume the scale, legal, distributive, and cryptographic responsibilities of running this chain for an indeterminate time period? How will privacy concerns be handled? Will each party continue to make the chain available? Is it possible to revoke party credentials?

Ecosystem vs Internal	Blockchains are a good for ecosystems but not necessarily for single entities. In single entities, in which trust already exists, other technologies and strategies can be used to ensure accurate record keeping.	Does the architecture support an ecosystem as opposed to a single company?
Inefficiency	Related to immutability, distribution and workflow, inefficiency is a concern for blockchain implementations and is derived from 3 aspects: 1) security framework and rigor required to operate the chain. 2) the fact that blockchains use a singly linked list as the data structure. 3) the transactional verification model associated with BFT.	Will the architecture support a blockchain's security overhead, search limitations, and transactional verification model? Can the participants support the required security? How will data be used? Will transactions need to be verified in real time? Will malicious actors be able to subvert the chain, or will the consensus model be complex enough to prevent this?

3.3.2 Accenture Tracking and Tracing report

This study, conducted by Accenture (2018) investigates the feasibility of blockchain to enable end-to-end supply chain traceability in the food sector. The study looks at the opportunities and challenges of implementing this emerging technology. It examined four different case studies, all involving different food commodities. The results of the study yielded a blockchain implementation process model along with a list of key practices. These illustrate key focus points that companies need to take into account when considering blockchain technology, specifically in a tracking and tracing supply chain application. The important components to a blockchain traceability solution are described below.

Leadership

Initiating a blockchain project requires a degree of digital transformation. Strong leadership is needed to spearhead its implementation. The human and social aspects of a project are often the most significant obstacles and can be resolved through proper guidance, communication and leadership. The leadership of such projects should strive to:

- Identify the business needs and value that needs to be delivered.
- Assess the technology and determine if it will add value.
- If blockchain can add value, identify the right partners and communicate the early stage vision.
- Allocate human and financial resources.
- Assemble the relevant supply chain actors and technology partners.
- Facilitate collaboration.

A Feasible Use-case

Whilst blockchain presents a tremendous opportunity to transform the supply chain, it is important to note that it might not be feasible for all use cases. It is important to assess the feasibility of each use case in order to determine suitable candidates. According to *Accenture* (2018) the minimum criteria for a valuable and achievable blockchain solution should include the following, listed in table 3-4.

Table 3-4 Criteria for a valuable and achievable blockchain solution

Market feasibility	The appropriate demand and market conditions are in place to enable participants in the market to be interested and benefit from participation. The solution must provide demonstrable business value and incentives for each participant in the blockchain ecosystem.
Technical feasibility	The technology is a good fit for the industry and its actors' needs. These needs should relate directly to the key benefits blockchain provides. Specifically, allowing multiple parties access to the same data.
Operational feasibility	There is sufficient capacity and coordination to enable adoption. This would include a practical and manageable governance model for effective collaboration, as well as capabilities, processes, training, and the like, to put the solution into practice, and sustain and scale the solution.
Financial feasibility	Introducing blockchain is financially feasible because the required capital is available to the actors who need it, and they can reasonably expect a return on investment, either through revenue increase or cost savings.

3.3.2.1 A consortium of partners and governance structure

Blockchain allows the sharing of data across a number of supply chain actors who currently, might lack trust or any other forms of data sharing. This consortium of partners might potentially include direct competitors as well as many other parties with distinct relationships. In order to enable the different parties to successfully work together on implementing a blockchain project, they need to be brought together to agree on various technical, organizational and legal matters regarding the blockchain. Examples of these are: method of consensus, governance, operating structure, technology solution, ownership of IP and liability. The common thread between these partners is the shared value derived from the blockchain implementation.

In order to build a successful consortium, a governance structure is needed to drive the intended value and desired behaviour from all participants. Participants and businesses will have to adopt new structures of working in an ecosystem that shares data to realize its full benefits. This is devoid from the traditional structure where each entity owns their own system and relies on data from within its perimeter. Organizations need to change the way in which they approach ownership of data, systems and supply chain operations.

3.3.2.2 Enabling technology

It is at the start of the supply chain where lack of transparency is usually the cause for issues further down the line, such as information availability to reliability of information on facts such as farming practices, location and labour management. Blockchain promises to be part of a solution aimed at addressing these issues, along with other enabling technologies and capabilities. To reap the full benefits of such a solution, it is important that digital transformation must occur, and especially at the base of the supply chain with the farmers and producers. Additional capabilities will be needed here such as access to digital technology, devices, mobile services, connectivity and infrastructure. This is to facilitate better information flow and data collection in the supply chain.

In a supply chain wide digital transformation, blockchain forms part of the end-to-end technology ecosystem and will be expected to interact with many existing technologies such as: ERP systems

(Enterprise Resource Planning), electronic ordering and payment systems, invoicing systems, logistics systems, order management systems and traceability systems to name a few.

3.3.2.3 Data accuracy, collection and entry

Whilst blockchain does facilitate greater transparency, it cannot ensure correct data entry. Methods and tools have to be applied that reduces the risk of incorrect data entry and to ensure the accuracy of information added to the chain such as data validation tools and data matching. This said the industry is moving towards greater automation of data collection, processing and entry with tools and technologies such as: product tagging (RFID, NFC-embedded ID chips), digital quality assurance checklists, GPS-enabled smart logbooks, IoT devices (scanners, sensors, cameras, etc.), smart packaging and digitized labelling, tamper-evident seals or security stickers and identity management of devices, commodities, and users.

3.3.2.4 Rules and Procedures

Rules and procedures need to be established between stakeholders to resolve issues such as: determining what data must be stored on chain, what types of data must be added, how new data will be added (choice of consensus mechanism), who gets to see what data etc. When a transaction is added to the blockchain, a consensus mechanism, among the stakeholders, determines whether that data is valid. This requires agreed upon rules by all stakeholders beforehand in a legally binding contract. Additionally, required data should be standardized across all supply chain actors involved. According to *Accenture* (2018), data standardization may mean adopting an already existing well known standard or creating a new one for the consortium. It is not necessary to standardize and agree on every piece of data, instead a good starting point would be to determine a small set of attributes that is required by all parties in the ecosystem. Not every piece of data needs to be shared.

3.3.2.5 Strong supporting ecosystem and incentives

Blockchain has the potential to unluck significant value for the different entities involved in the supply chain, if designed and operated with the right incentives in mind. There must be sufficient incentives for organizations to change and offer performance and operating improvements on compared to current processes.

3.3.2.6 Key practices from case studies

- Certain use cases can be prioritized based on value provided and operational and market feasibility conditions.
- Developing a successful blockchain initiative requires identification of the right use case and involvement of a group of parties that can align their incentives.
- Sharing product data on the blockchain is key to establishing and tracking provenance; what data should be on- versus off-chain requires careful consideration.
- Robust, reliable, and standardized data is best captured using data-capture technologies, such as Internet of Things (IoT), sensors, and smart tags.
- Interoperability between the blockchain system and enterprise systems across diverse actors in the supply chain is critical; user experience should be considered at each level.
- Sensitive data on key actors and their food commodities should always be protected in an ecosystem that impacts global consumers and capital markets.
- A trusted, neutral third party that plays an audit or certification function could be beneficial

to increase the level of trust of each participant (and the data that they enter into the system).

- A blockchain traceability solution should consider the implications of cross-platform interoperability.

3.3.3 Do you need a blockchain decision framework

A research article published in IEEE Spectrum showcases a decision framework that aims to determine if use cases can make use of Blockchain technology and if so, whether the use case is better suited for a private or public ledger. The research explores the advantages and disadvantages of the technology and has developed a set of questions focusing on key aspects that one should base the decision of using a blockchain, on.

According to Peck (2017), there is a strong case for blockchain when:

- A traditional database does not meet the needs of the project
- There is more than 1 entity/participant/company that needs to update data.
- There is not a sufficient level of trust between all the parties involved.
- All participants in the network would not be able to place trust in a 3rd party.
- There is a likelihood of data being attacked/falsified/censored and thus the solution needs data redundancy on multiple computers.

More so, if the above criteria is met, a strong case for a permissioned (private) blockchain can be made if:

- The desired data, that must be uploaded to the blockchain, needs to be kept private.
- There needs to be a control mechanism for which entity/stakeholder can make changes to the blockchain or is allowed to upload data.

3.3.4 A practical framework for business leaders

The World Economic Forum published a white paper titled *Blockchain Beyond the Hype: A practical framework for business leaders.* It presents a practical framework for business executives to understand whether blockchain is appropriate and helpful for their business needs. This tool is based on lessons from real life projects involving blockchain technology across a variety of industries. It was constructed by members of the *World Economic Forum's Global Future Council on Blockchain* and has been trialled in a variety of scenarios. It aims to provide rapid analysis of whether blockchain is an appropriate solution to a defined problem. The frameworks consists of 12 questions, each focusing on an important criteria that either leads either towards or away from the use of blockchain technology. These 12 questions will be examined below.

Intermediaries

Is the goal to remove intermediaries? If blockchain is the appropriate solution, the business problem should be aiming at the elimination of an intermediary.

Digital Assets

Are you working with digital assets? In a blockchain solution it is important that physical assets can be digitized. In simpler terms, can digital representations of physical assets be created? If yes, then blockchain could be a possible solution.

Permanent records

Can one create a permanent authoritative record of the digital asset in question? This is a critical question as blockchain is a source of trust. If the use case needs a record where data must be altered or deleted, the blockchain will not be the appropriate technology in question.

Transaction Performance

Do you require high performance (rapid millisecond performance)? In current developments, blockchain transactions speeds are slow compared to those in traditional databases or financial systems (minutes vs milliseconds). If high transaction processing speeds are a prerequisite, then blockchain is currently not a suitable solution.

Data Storage

Do you intend to store large amounts of non-transactional data as part of your solution? It is not currently advisable to store non-transactional data on a blockchain according to Mulligan, et al. (2018).

Trusted 3rd party

Do you need to rely on a trusted party? If an industry has specific requirements on the use of 3rd parties or intermediaries, then it may complicate the deployment of blockchain. In use cases where regulation plays a substantial role, it may be necessary to include regulators in the project. If a trusted 3rd party is needed, then blockchain may still work, yet the solution will need further research and refinement. If this is not the case, then the case for blockchain is stronger.

Contractual relationships vs value exchange

Are you managing contractual relationships or value exchange? For blockchain to assist in reducing costs and delivering business value, it is important that it looks at managing transactions around digital assets. If a business problem does not involve the management of contractual relationships or value exchange, then there is little need for the technology.

Shared write access

Do you require shared write access? In other words, do all the members of the network require the ability to write transactions to the blockchain? If this is not the case, then there is most likely a better technology than blockchain for the application.

Trust

Do contributors know and trust one another? If there are strong levels of trust throughout the participants in the network, then there is no reason for the use of blockchain. Blockchain can be used to foster trust in environments lacking it.

Alignment of interests

Are contributors' interest well aligned? If all participants in the network have aligned interests, then it provides a stronger case for the use of blockchain. Even though the different members may be competitors, or not have direct business relations, if a common thread of value can be found such as the tracking of products for example, then it strongly supports the use case of blockchain.

Control

Do you need the ability to control functionality? If the ability to change the functionality of certain blockchain protocols, such as permissioning, rules, node distribution etc., is desirable without having large detailed discussions, it strengthens the case to have a private permissioned blockchain.

Public vs private

Should transactions be public? If transactions need to be kept private or only available to a preselected amount of entities, then a private blockchain would be the more suitable choice. If not, a public blockchain would be the better approach.

3.3.5 Use case canvas and framework for exploring blockchain opportunities

The research article '*A Use Case Identification Framework and Use Case Canvas for Identifying and Exploring relevant Blockchain Opportunities'* introduces a use case identification model and a use case canvas. The frameworks helps practitioners identify which use cases are suitable for blockchain technology whilst the canvas enables deeper insights into how such a use case will be structured. Concerning the framework, *Klein, et al* (2018) evaluates a use case using three categories: Intermediaries, Data and Process.

Intermediaries

Since blockchain functions as an independent and incorruptible intermediary, blockchain can result in one of 3 scenarios. It can either:

- Replacing an excising intermediary. In this situation blockchain replaces the role of a 3rd party for increased efficiency or operational gains.
- Establish itself as a new intermediary. Applicable to situations where there is no intermediary due to a lack of trust blockchain can be the technology that facilitates trust between a network of untrusted partners.
- My business model. This describes the situation from the view of the intermediary who's business might be replaced by blockchain. Possibilities to change the existing business model needs to be explored in order to prevent disruption from the new technology.

Data

The second category, data, assesses the use of data in a blockchain based network. Blockchain technology offers the possibility to save data permanently and transparently as well as preventing anyone from modifying the data after it has been entered into the blockchain. Thus the use case must highly value the fact that data has to be immutable and saved permanently for transparency across the network.

Process

The third category assesses the use cases' potential for automation. Since blockchain enables the use of smart contracts to automatically trigger transactions, those contracts can be used for automation purposes and thus for making the process more efficient. If use cases can benefit from this automation, blockchain would be a well aligned solution.

The assessment of these three categories can help determine if the desired use case would be suited to adopt blockchain technology. The more positive the last two categories are rated, the more suitable blockchain is for the use case (Klein, et al., 2018). The next step is identifying how blockchain will impact the use case. The use case canvas presents five categories which collectively describe relevant characteristics of a blockchain that would be suitable for a specific use case. The categories are: '*added value, data and process integrity, decentral network, values and rights, and automation'*. For each category, the user can list the relevant aspects concerning the category and give it a rating from high to low depending on its importance in the use case.

Added value

This category is concerned with what difference blockchain makes when compare to the use case implementation without the technology. Relevant aspects are: which tasks are being supported? Which processes are being improved? What unique characteristic is being achieved? Overall this category evaluates how blockchain improves specific aspects.

Data process and integrity

This category identifies which data has to be managed securely. After establishing that there is data in the use case that needs to be immutable, permanently stored and visible for all, the next step is to determine what is the exact pieces of data that needs to be stored.

Decentral network

This is one of the most important aspects and should document who are the different partners that will form part of the network.

Values and rights

As blockchain is concerned with the transfer of values and rights between partners in a network, the user should identify and specify what the values and rights are that is being transferred in the use case.

Automation

The last category, automation, describes which parts of the use case can be automated. If a certain potential for automation was identified, in use case identification framework, the canvas can then be used to specify which processes/tasks in the use case can be automated by blockchain.

3.3.6 Evaluating the suitability of applying blockchain

As a database and computational platform, blockchain has both advantages and disadvantages compared with conventional techniques. Blockchain may be an appropriate choice for some use cases while conventional technologies will be more appropriate for other use cases (Lo, et al., 2017). To date, there has been little decision support for practitioners considering blockchain In the paper titled '*Evaluating Suitability of Applying Blockchain*', the researchers presents a framework that assesses the suitability of applying blockchain against conventional databases. It uses criteria based on the characteristics of real world use cases to formulate the framework. These criteria were formulated into a list of questions, each focusing on a certain specific criteria. The answers to these questions either lead towards the application of blockchain, or towards the use of a conventional database. The different characteristics are listed and evaluated in the following section.

Multiparty

The first question is whether multiple parties are involved or required. The operations of transactions between parties are normally governed by intermediaries such as in supply chain environments. Blockchain provides a shared neutral infrastructure where none of the parties involved are able to dictate it. Thus, blockchain is more favourable for multiparty applications as opposed to a traditional database, more suited to single entity applications. The benefit of blockchain is that it would be able to break down the silos of information controlled by individual parties to generate an ecosystem of information, increasing speed and efficiency.

Trusted authority

The second question is whether a trusted authority is required in the scenario, which is an entity with the authority to execute certain operations and make alterations. Blockchain is suitable for scenarios without any trusted authority or the current trusted authority has potential to be decentralized (Lo, et al., 2017). Users are shifting their trust from central authorities or trusted third parties to the blockchain where there is a universal incentive for good behaviour.

Centralized operation

The next step is to question whether the operations on the application is centralized. In smart contract based blockchain systems, system operation is harder to govern. This is because smart contracts comprise of code that regulates the interactions between mutually untrusting parties - trust is derived from the fact that the code cannot be changed easily. By implementing blockchain-based systems, no single party can control the system, instead each user is in control of their own data and assets. Thus the current configuration of blockchain systems is not suitable for solutions that require central operation.

Data transparency vs confidentiality

The fourth question is to determine whether data confidentiality or transparency is required. Blockchain provides a neutral platform where all participants can view published data. Encrypting data and uploading it to the chain increases confidentiality but may reduce transaction speed, transparency or independent audibility. Another option is storing only the hash of data on chain, keeping the raw data off-chain. This increases the performance and confidentiality but in essence undermines the distinctive benefit the blockchain, providing distributed trust. Greater transparency is in a trade-off with confidentiality, even if pseudonyms or encryption is used. The main trade-off is between the ability to share data visibly between a group of collaborators, and retaining confidentiality where needed, such as between competitors. If transparency is required then it provides a stronger argument for the use of blockchain. The solution to the case where transparency is not required is if data can be shared with encryption.

Data integrity

The next question is to determine whether the integrity of the transaction history is required. Blockchains data integrity is a key feature in its ability to provide provenance. It has the ability to track assets as they move through the supply chain and changes ownership between the different entities. However, using blockchain to create provenance may be expensive when compared existing methods such as hashing technology or the ability to cryptographically sign data. An architecture with existing methods to prove provenance might not benefit from the added provenance that blockchain adds. Thus blockchain is only suitable in cases where transaction history is required.

Data immutability

Is data immutability required? In environments where there are no trusted 3rd party service providers, the benefit of blockchain is that it can offer strong support with a system that contains immutable historic transactions. Once data is uploaded, it cannot be changed because it is replicated across a large network of different locations and organizations. This is usually of an advantage, however in the real world, problems may arise such as: disputed transactions, incorrect addresses, exposure or loss of private keys, data-entry errors, unexpected changes to assets tokenized on the blockchain or if a court orders illegal content to be removed from the blockchain. Concerns around a perfectly secure historical record of transactions must be considered during the design process. Its immutability may make it less adaptable when compared to conventional technologies which are controlled by trusted third parties who offer support.

High performance

The final point is whether high performance is required. Currently, blockchains are not highly scalable. A limitation which will most likely be overcome in the future. If properly designed, private blockchains can offer higher performance gains when compared to public blockchains. This said, blockchain is not the most efficient method for storing large amounts of data. This is due to the massive redundancy (copies) of data stored across all nodes participating in the network and the speed at which data needs to move. The current solution to this is to store data off-chain to avoid duplication to all networked peers. However as mentioned, this counters the true intention of blockchain of providing a transparent immutable history of transactions and data on-chain. Thus, if high transaction performance is required, a conventional database would be better suited as opposed to a blockchain.

3.3.7 Case studies and other supporting papers

Other design guidelines, principles and important considerations surrounding the design of blockchain based track and trace solutions in the supply chain were extracted from research papers and other resources. Technical design considerations and knowledge on blockchain based systems were extracted from these sources, some of which was presented in chapter two.

Table 3-5 Supporting papers and resources

	Resource	Author
-	Consensus: Immutable agreement for the Internet of value	(KPMG, 2016)
-	A Taxonomy of Blockchain-Based Systems for Architecture Design	(Xu, et al., 2017)
-	Blockchain use cases for food traceability and control	(Kairos Future, 2017)
-	Blockchain's roles in meeting key supply chain management objectives	(Kshetri, 2018)
-	Blockchain characteristics and consensus in modern business processes	(Viriyasitavat & Hoonsopon, 2019)
-	Performance Analysis of Hyperledger Fabric Platforms	(Nasir, et al., 2018)
-	The Blockchain: A Comparison of Platforms and Their Uses Beyond Bitcoin	(Macdonald, et al., 2017)
-	Tracking and tracing with Blockchain	(Palamara, 2018)
-	Comparison of Ethereum, Hyperledger Fabric and Corda	(Valenta & Sandner, 2017)

3.4 Reference Architecture Design Process

In the previous section, different frameworks were analysed and the various key factors and requirements for blockchain based systems were extracted and examined. In this section, an overview will be given of the processes used to formulate the structure of the design reference architecture.

3.4.1 Collection of the different requirements from sources

In order to generate a visual overview of the different requirements, a colour coded chart was constructed, organizing the different requirements collected by source. In this way, one can better identify the similarities and differences between the various requirements. The next step is to identify the common characteristics between the different requirements.

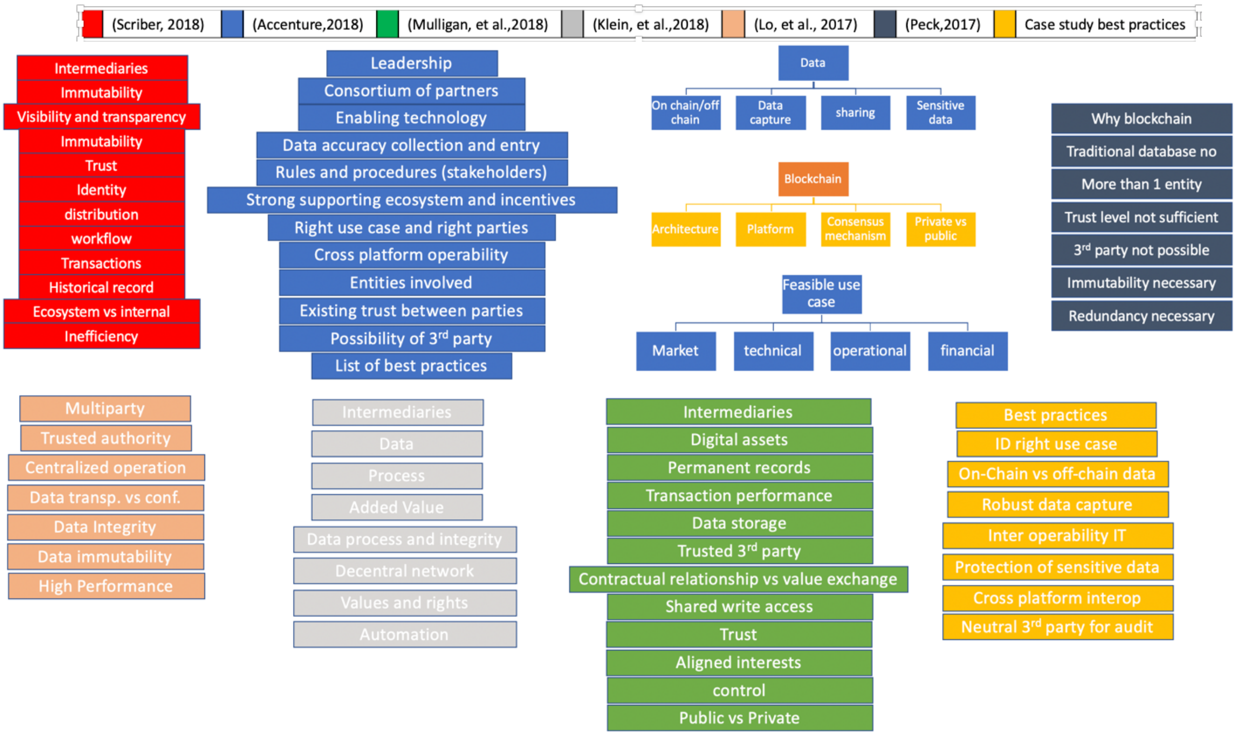


Figure 3-10 Overview of requirements collected

3.4.2 Initial grouping and characterising of different requirements

After obtaining a visual overview of the different requirements, its apparent that there are four main categories that can be used to initially group them, explained in table 3-6. This is a very broad categorization of the but it aids to obtain an initial overview of topics covered.

Table 3-6 Description of initial categories

Data	Requirements or factors that relate to capturing and storing data on the blockchain. For example, the decision of what data to store on-chain and off-chain.
Technology and IT	These factors relate to blockchain itself and various other technology aspects: For example, the importance of blockchain to be able to operate across IT platforms.

Strategy	This section includes requirements that relates to a company's digital strategy regarding the use and deployment of blockchain in the supply chain. For example, deciding on whether the strategy involves the creation of a supply chain ecosystem, or rather, a focus on internal processes.
Stakeholders	The stakeholders section involves factors and requirements that relate to the different supply chain stakeholders (companies, partners, 3rd parties, suppliers, distributors etc.) in a blockchain network. It involves activities such as stakeholder leadership and considerations such as who has values and rights in the network.

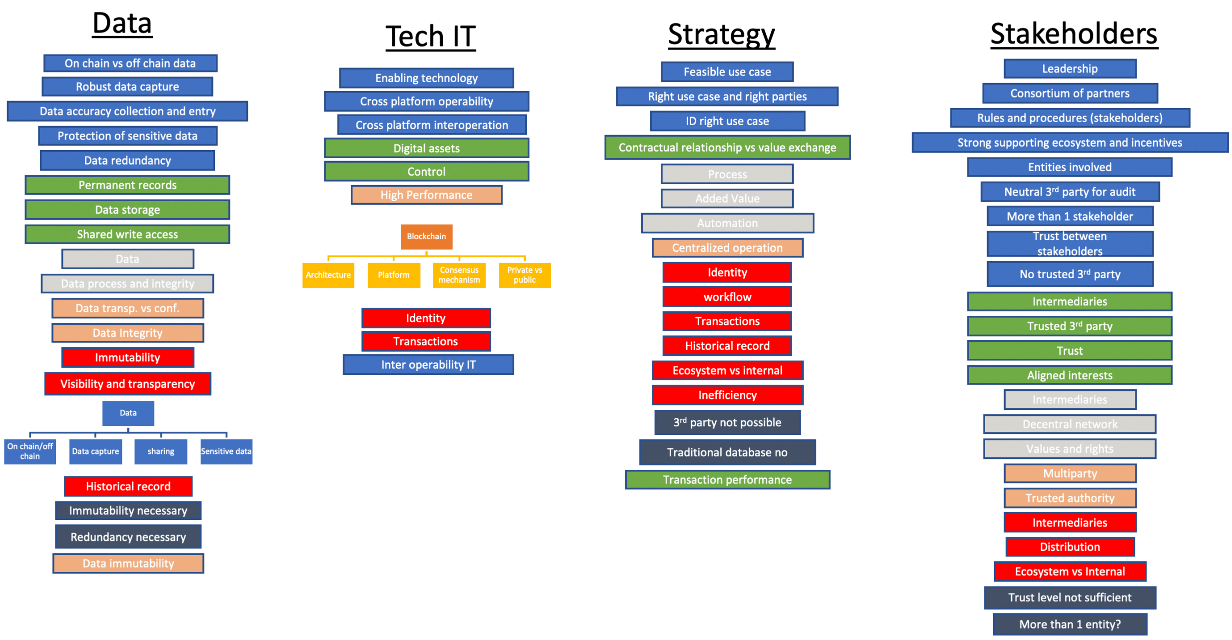


Figure 3-11 Visual representation of categorized requirements

3.4.3 Further refinement and identification of common requirements

After evaluating the requirements under each category, it is apparent that there are many similarities between them. The main ideas from each can be summarized in table 3-7 below.

Table 3-7 Main ideas from each requirements category

Requirements relating to:			
Supply Chain Data	Technology and IT	The Overall Strategy	Stakeholders involved
The identification of supply chain data.	Choices with regards to blockchain platforms, architecture, consensus mechanisms and mode of operation.	Analysis of use case feasibility.	Leadership activities.
Privacy and security of data.		Ecosystem vs internal / centralized vs decentralized operation.	Consortiums and governance structures.
Data capture and entry.			Values and rights.
Data requirements.	Other IT related requirements such as cross platform operation	Contractual and value exchange on the supply chain.	Identification of different stakeholders and 3rd parties.

	and digital enabling technologies.	Management of identity and transactions on the supply chain.	Levels of trust in the supply chain. Stakeholder ecosystem
		Value chain, workflow and efficiency.	Incentive for different stakeholders.

3.4.4 Formulation of the architecture's structure

Thus far, a general idea has been obtained regarding the different components covered in the architecture. It is known that there will be a section dedicated to the technical aspects of blockchain in the supply chain. This will involve the different data related requirements and requirements of blockchain technology itself. Another important part is the role of blockchain within the supply chain. There are many factors that relate to the different supply chain stakeholders, such as governance structures, incentives and rights; including factors relating to supply chain processes, such as transactions, workflow and value chain. In terms of the overall strategy, a main requirement highlighted is the feasibility analysis of use cases. When examining the case studies, it was found that it is important to first ask the question, "*why blockchain*"? What is the reason for using blockchain over another technology? Is this application suited for blockchain technology? The common problem companies face today is to determine why blockchain is necessary in the first place. This means that one would first have to examine feasibility and overall strategy before examining the more technical aspects.

Another factor that was made clear in the case studies is that there has to be a strong case motivating the choice of product to be tracked and traced. The product should have a specific characteristic that adds to its value and thus motivates the need for it to be tracked and traced. These products often makes claims such as: '*non-GMO', 'ethically sourced', 'from a certain region', 'environmentally friendly'* etc. These characteristics have to be strongly related to the identity of the product and must be digitized to form a digital product identity. In light of the findings from the case studies, there has to be a section in the architecture dedicated to the actual product that is tracked and traced. This section has to highlight the case for the product and identify its characteristics and requirements in order to form a digital product identity.

3.4.5 Summary of findings

After these evaluations, a general idea can be sketched of the design reference architecture structure. The main components are displayed in the figure 3-12 below. Each of these components will house various sub-structures that will bring together requirements, considerations, guidelines and principles that is key to the design of a blockchain track and trace system in the supply chain.

The TOGAF architecture was used as a general inspiration to the design of reference architectures for information systems. A relation can be drawn between the sub-structures of this architecture and the sub-structures of the TOGAF architecture, specifically the vision (strategy), business (SC architecture) and technology & information system (technology) sub-architectures.

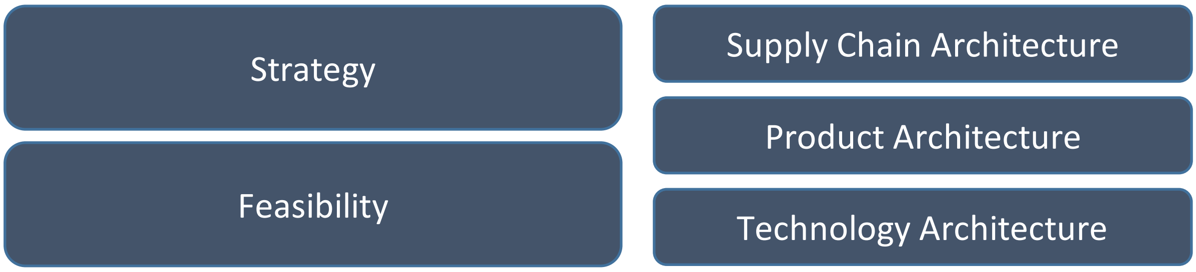


Figure 3-12 Summary of the architecture components

Chapter 4 Design Reference Architecture

In the previous chapter the following tasks were completed: A methodology was outlined for the design of a blockchain reference architecture, blockchain design requirements were extracted from relevant sources and the requirements were characterized in order to help formulate an architecture design. The aim of this chapter is to present the design reference architecture developed. It starts off with an overview of the main architecture. Following this, each of the sub architecture sections will be examined and explained in detail.

4.1 DRA description and overview

4.1.1 Main structure

Figure 4-1 provides an overview of the Design Reference Architecture (DRA) that has been developed. It is comprised of five sections, each of which houses different sub-sections that are of importance in the design of blockchain implementations for tracking and tracing. The arrows and dividers show the interrelation between the different sections of the DRA. The core set of principles and design considerations are housed within the Product-, Supply Chain- and Technology architecture sections. These are the main sections that specifically relate to blockchains' design principles and considerations in tracking and tracing. The Strategic Intent section houses general overall guidelines that are important for the digital transformation of supply chains such as with tracking and tracing with blockchain. The feasibility section contains specific questions that are aimed at testing the feasibility of a the blockchain supply chain venture being analysed. These questions are derived from important considerations that must be met in order to determine if the given venture is feasible for blockchain adoption.

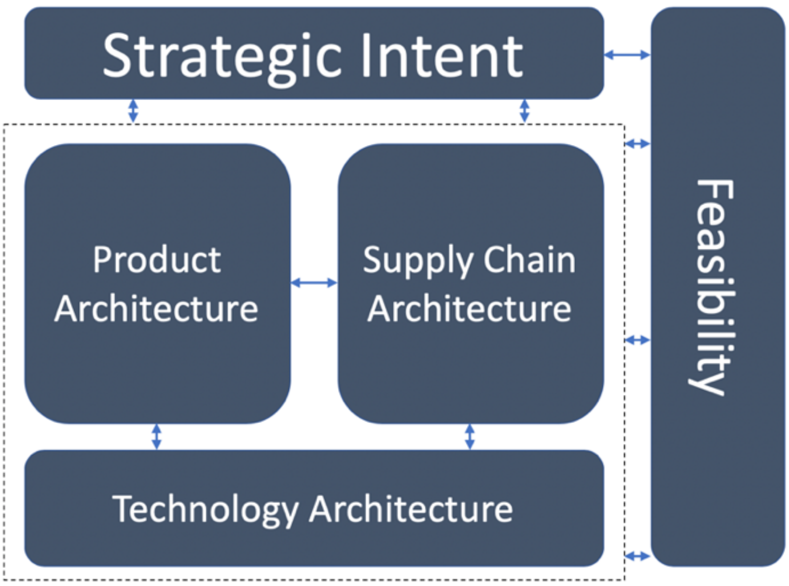


Figure 4-1 High level view of architecture structure

Figure 4-2 showcases the expanded view of the DRA in which the different subsections and components covered are visible. Each of the individual topics listed below houses the important design guidelines and considerations/principles/requirements that need to be taken into consideration. For simplicities sake, each of these design principles/considerations/requirements will be called a guideline. After all, that's what they are indented to do, to help guide the process of designing a blockchain based supply chain. When designing the DRA, it was decided to group all the individual guidelines by their relative overbearing topics to which they relate.

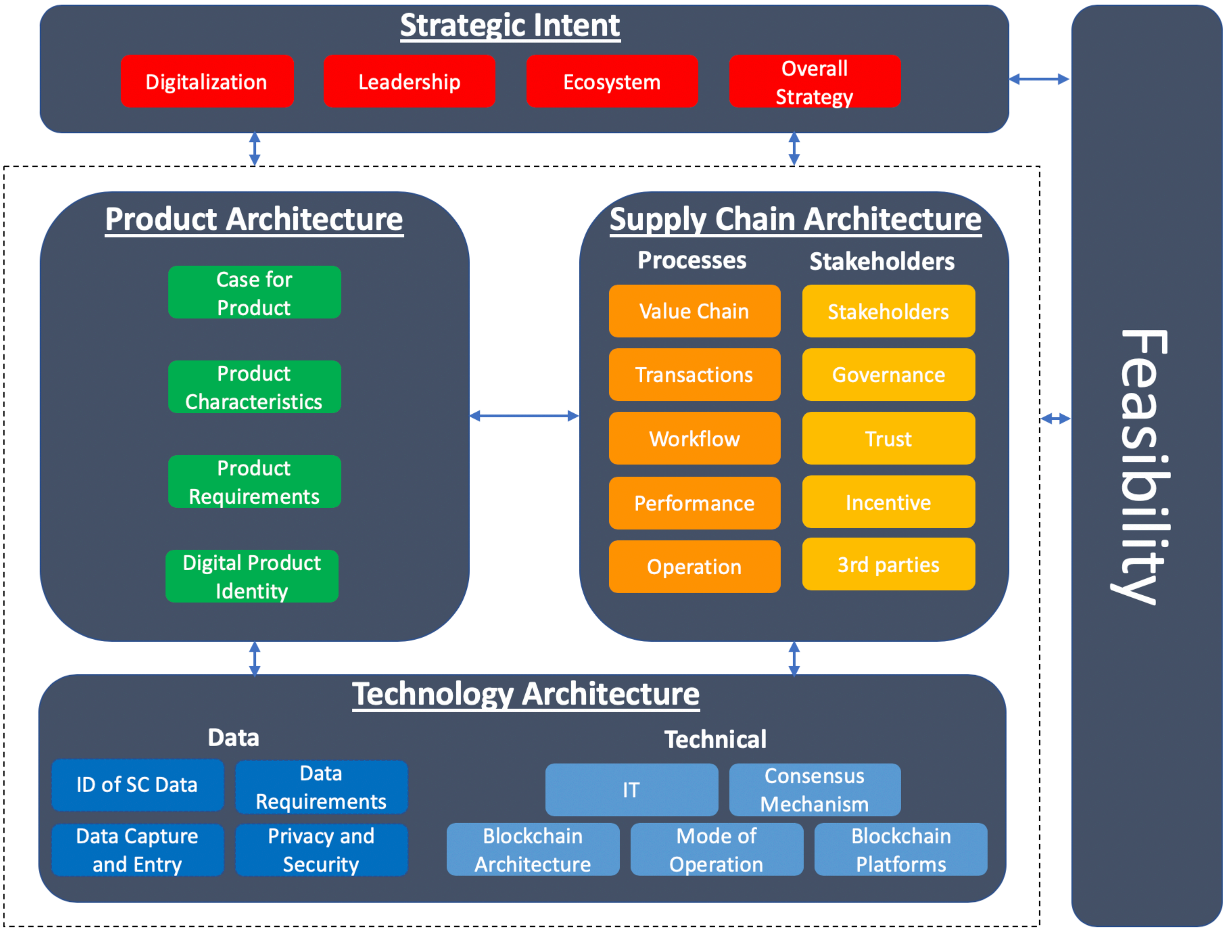


Figure 4-2 Overall view of reference architecture, sub-architecture and components

4.1.2 Logical flow

The logical flow of the architecture is as follows: One starts on the outside with the feasibility and strategic intent sections. This helps determine whether blockchain is suited to the application in question and to give an overview of the strategic activities required for that project. After that one moves into the centre to the product, supply chain and technology architecture to get more in depth guidelines relating to each section.

4.1.3 An example of how guidelines fit into the overall architecture

Figure 4-3 provides an example of how a single guideline fits into the overall reference architecture. In this case, the guideline is as follows: '*It is important to identify what the various data flows are surrounding the supply chain in question, before commencing with the design of the blockchain tracking and tracing system*'. This guideline relates to the topic of '*Identification of Supply Chain Data*' which groups a few relevant guidelines. As this topic is in relation to understanding the data that needs to be stored on the blockchain, it falls under the '*Data'* subsection which is housed within the overall '*Technology Architecture*; section. This section is representative of all guidelines that relate to blockchain technology itself and the aspects relating to IT and data. This is an example of the methodology and thought process used to incorporate individual guidelines into the overall architecture. In the next subchapter, each section of the reference architecture will be described in detail. This will serve as a comprehensive accompanying description on how to use the Design Reference Architecture and understand the implications of the various guidelines.

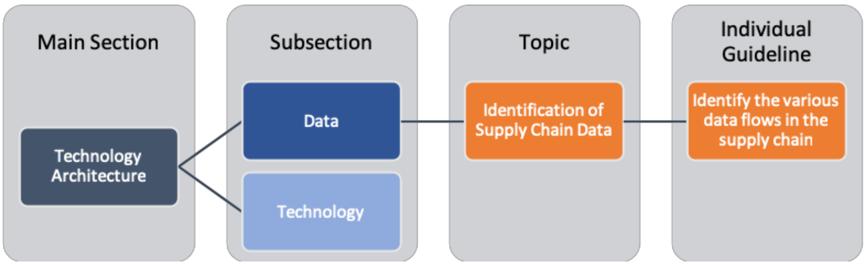


Figure 4-3 Example of architecture composition

4.2 Strategic intent

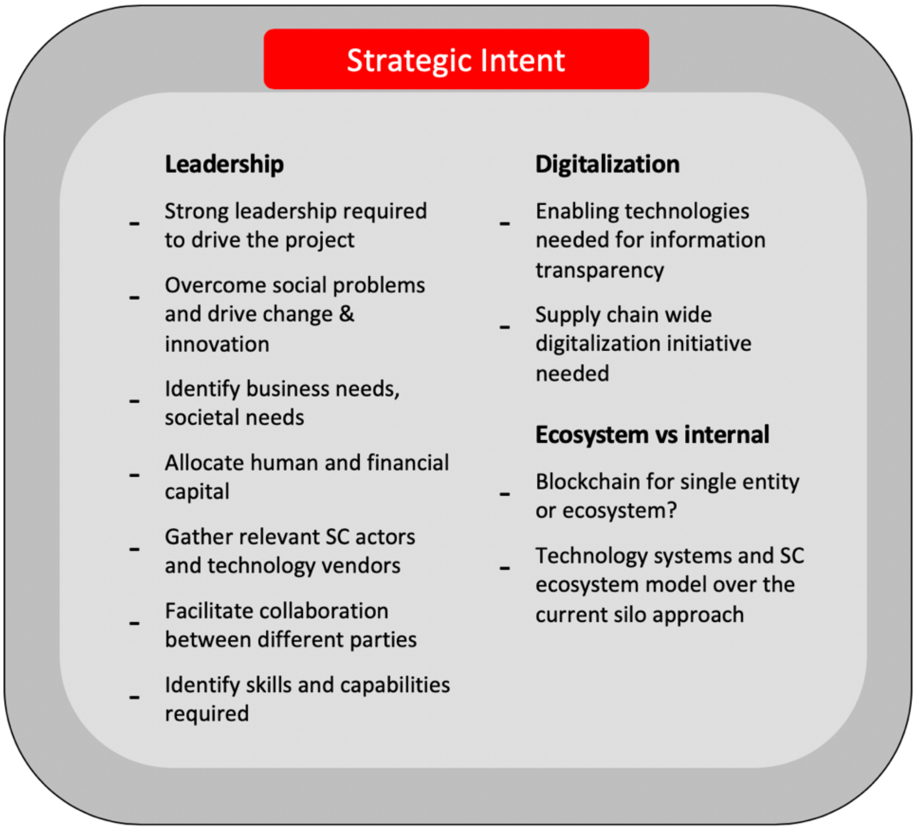


Figure 4-4 Detailed view of strategic sub-architecture

The strategic intent section relates to the overall supply chain strategy that should be considered when embarking on a blockchain tracking and tracing supply chain solution. Its location on the DRA is on the outside of the main section which implies that its guidelines are related to overbearing supply chain digitalization strategy. Figure 4-4 showcases the expanded view of thus sub-architecture. These are generic guidelines that should be considered when applying a new technology such as blockchain to a supply chain. They deal with challenges such as the importance of strong leadership in order to drive digitalization initiatives throughout the network. It also highlights the importance of viewing digitalization as an ecosystem approach rather than the traditional silo model.

4.2.1 Digitalization

- Enabling technologies
- Digitalization initiatives

Blockchain technology is only part of the tracking and tracing solution. It requires a host of other enabling technologies and digitalization initiatives across the ecosystem. The key to this solution is information availability and reliability. Blockchain alone cannot solve the existing manual processes, lack of connectivity, the digital divide, inadequate quality of data input etc. To reap the full benefits of blockchain, a host of other enabling technologies need to exist and be deployed in the supply chain. This is true especially at the base of the supply chain where there is often a lack of digital initiatives and capabilities. As such, it is here where technologies and capabilities for data collection and entry need to be considered. In order to digitally track and trace a product across a supply chain, technologies such as mobile connectivity, IOT sensors, GPS sensors, RFID, barcodes and scanners will be needed to link data from the product and its environment to the blockchain network online.

As information relating to a product's journey through the supply chain is key, it is expected that a blockchain system would need to interact with many other information systems currently in use throughout the supply chain. This is because blockchain would most likely not replace systems, but act as an application layer operating above other information systems that are in place in many of the supply chain parties. Table 4-1 provides an overview of systems that blockchain is expected to integrate with.

Table 4-1 Current technologies expected to interact with blockchain systems

Existing technologies expected to form part of or interact with blockchain systems	
- Enterprise resource management (ERP) systems	- Logistics systems
- Electronic ordering and payment systems	- Order management systems
- Invoicing systems	- Traceability systems

4.2.2 Leadership

Implementing a supply chain wide initiative, such as a blockchain tracking and tracing solution, has a host of technological and architectural hurdles that need to be navigated. However, in a project, such as this, that involves multiple stakeholders throughout the supply chain network, it is often the social problems that are the most significant obstacles to success and that cannot be solved by technology.

Strong human leadership is required to spearhead the change and innovation needed for such an initiative. Leadership should focus on the following activities presented in table 4-2.

Table 4-2 Leadership activities relating to blockchain implementation

Important leadership activities for blockchain implementation
- Identifying the business or societal needs and focus on value that needs to be delivered.
- Assess if blockchain would add value and address current problems.
- If blockchain can add value, identify the right consortium partners (stakeholders) and provide early stage vision for innovation and collaboration.
- Allocate the initial human and financial resources.
- Identify what skills and capabilities are required.
- Gather relevant supply chain actors and technology vendors.
- Facilitate collaboration between all the different stakeholders, partners and vendors.

4.2.3 Ecosystem vs Internal

- Current silo approach vs digitalization ecosystem model

Blockchains are a good fit for ecosystems but not necessarily for a single system entity. This is because blockchain solves trust issues and generally these issues are inclined to occur when multiple parties are involved in an initiative. Single systems, such as companies, have other mechanisms and technologies that deal with creating internal trust. The company should evaluate whether the blockchain solution in question is aimed at creating a supply chain ecosystem or just solving an issue relating to one company in the SC network.

4.3 Product architecture

Blockchain is often portrayed as a technology that will offer improvements and disruption to any application to which it is applied. As with any new technology this is most often not the case. There are select circumstances to which it is best suited. The challenge is to determine the situations, or in this case, products, which are suited to blockchain application.

This fact holds true with tracking and tracing in supply chains using blockchain. The product architecture section aims to provide guidelines necessary to determine the supply chain product that is best suited for blockchain adoption. These guidelines are shown in the expanded view in figure 4-5. Supply chains, especially food supply chains contain a plethora of different products that move throughout the supply chain network. Supply chain actors have to identify which products, and consequently which supply chains are best suited to blockchain adoption.

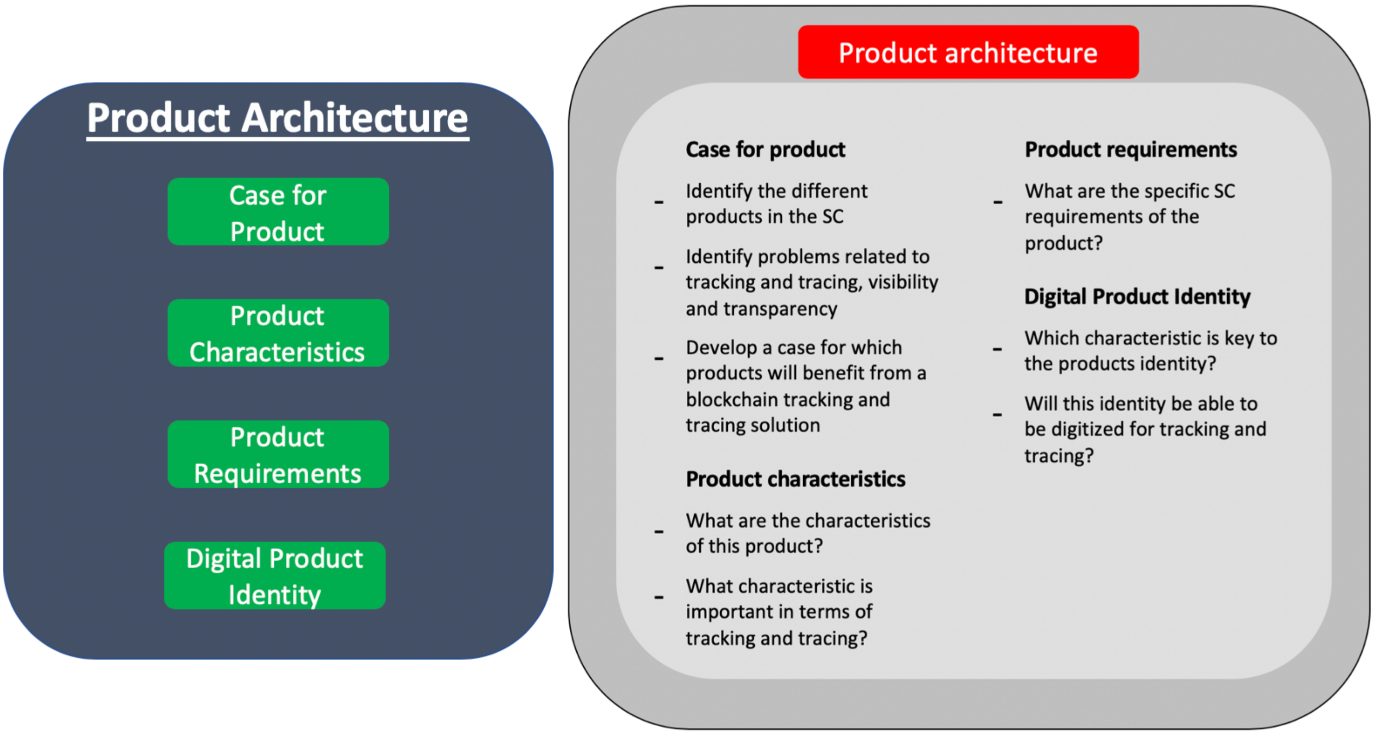


Figure 4-5 Detailed view of the product sub-architecture

4.3.1 Develop a product case

It is important to first develop a defined case for the product. In other words, the reason why this product and its supply chain is best suited for blockchain adoption out of other possible cases. The guidelines are to first identify the different products and supply chains under consideration, then identify all the problems, bottlenecks or issues that relate to lack of transparency and supply chain visibility. Following this, a case should be developed for which product will benefit most.

From past blockchain case studies in the food supply chains, there are certain key indicators for products that are better suited to blockchain adoption. Blockchain for tracking and tracing is ideal if the product in question has a specific identifiable characteristic that is of value to both the market and the supply chain parties. Also, a product is ripe for blockchain tracking and tracing if the market value of the product is related to either its location of origin, specific nature or way in which it was produced. Blockchain is ideal for keeping a secure record of the product identity as it moves between parties in the supply chain all the way into the hands of the consumer. If the assurance of the product's value or identity can be tied to this immutable/visible record, then the benefits of blockchain technology can be applied to the supply chain.

4.3.2 Determine the product characteristics and requirements

As mentioned, products with specific characteristics of value have a stronger case for blockchain adoption. Their characteristics can either be important to the market, supply chain parties or both. The different product characteristics have to be identified in order to determine which characteristics are important in terms of tracking and tracing. It is also important to identify what the specific supply chain characteristics are of the product. This can relate to any method of production, transportation, storage or location of origin that specifically relate to a product.

4.3.3 Digital Product Identity

Once the different product characteristics are established, it must be determined which of these characteristics are key to its identity and whether this product identity can be digitized for tracking and tracing. Forming a digital product identity is key as information relating to the product has to be uploaded to the blockchain network as the product moves throughout the supply chain. In order to do this, you need a product whose identity is digitizable and also the enabling technologies to digitize the product at each stage of the supply chain. The digitization capabilities of the supply chain will be examined at a later stage in the reference architecture.

4.4 Supply chain architecture

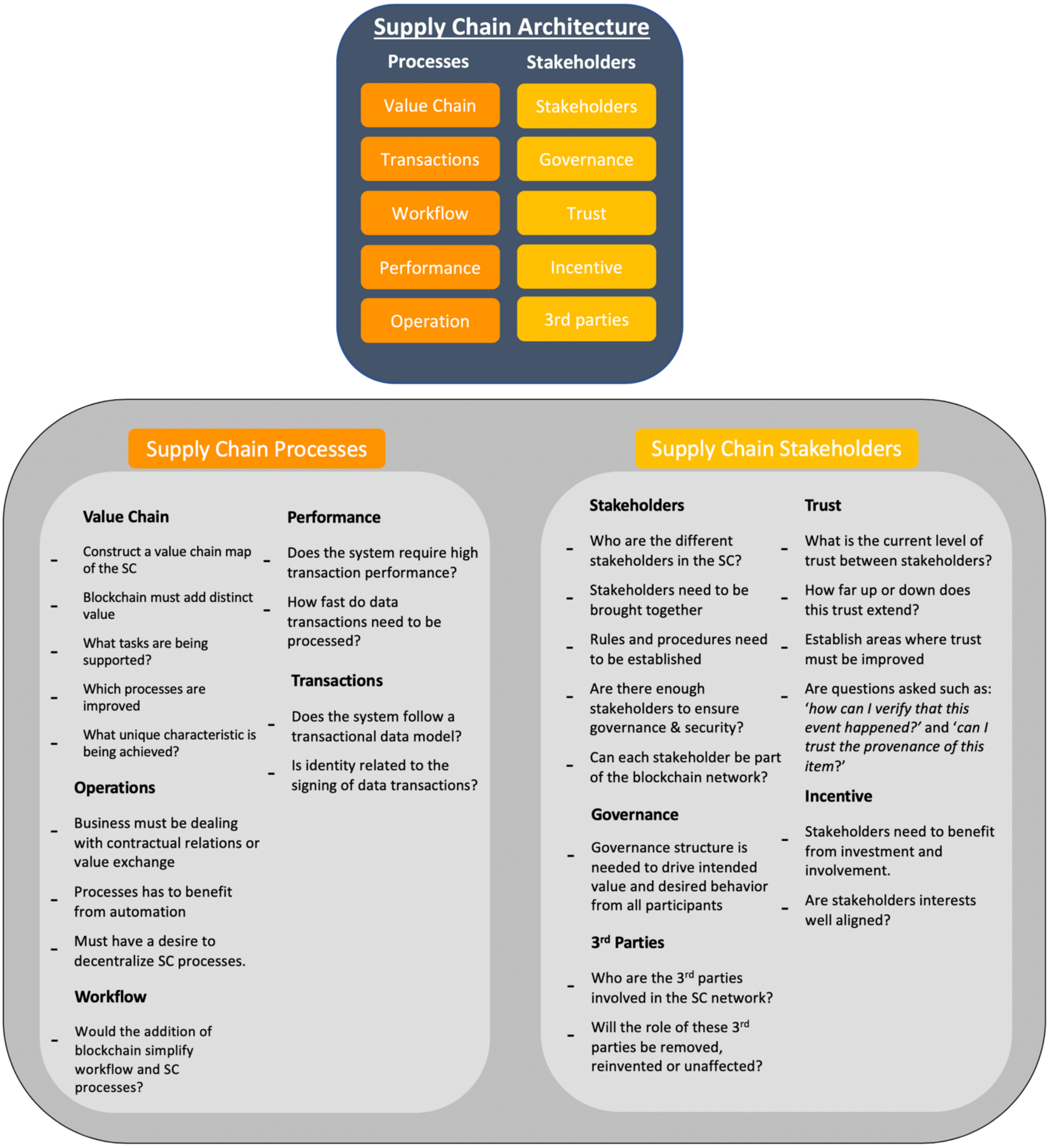


Figure 4-6 Detailed view of the supply chain sub-architecture

When blockchain is approached as a solution to supply chain visibility, it is easy to get caught up in the complex technology side of the problem, that one forgets the many other supply chain management aspects that are involved. This section of the design reference architecture is concerned with these supply chain aspects that are important to consider with the application of blockchain technology. It contains important guidelines including the identification and governance of stakeholders as well as identifying where the added value is, to name but a few. This part of the architecture is divided into two-sections; Supply Chain Processes presents general guidelines surrounding the value chain, transactions, workflow, operations and performance of blockchain in the supply chain, whilst Supply Chain Stakeholders focuses more on the guidelines surrounding trust, incentives, 3rd parties and governance related to the stakeholders involved in the blockchain network. The various guidelines are described in detail in the following sections.

4.4.1 Supply Chain Processes

Value

The value chain is a representation of all the activities performed to design, produce, commercialize, deliver and sustain a product (Monteiro, et al., 2017). Value chain mapping is the process of identifying all the main activities and processes associated with producing a product in the supply chain. It is an important practise to conduct a value chain analysis for blockchain technology in the supply chain. Blockchain must add distinct value when compared to the current system or alternative solution. By doing this they can determine blockchains best fit within the supply chain The practitioner must determine:

- Which tasks are being supported by blockchain?
- Which processes are being improved?
- What unique characteristic is being achieved with the use of blockchain?

Transactions

Applications will benefit where identity is strongly related with the signing of a transaction. Identity supports ecosystems in which there is a requirement to know the item, individual or system involved in the transaction. This could encompass knowing:

- who performed the transaction.
- what are the details of the transaction.
- which product is involved.
- how has ownership changed.
- how something was moved through the workflow.

Additional considerations are knowing what transactional elements are important to associate with identity and whether network participants must be mapped to the transactions.

The next consideration is to determine if the system follows a transactional data model. As blockchain is a visible ledger of transactions it traditionally is best suited to systems where there is an exchange of information between parties in the form of a transaction. If the current proposed system does not follow a transactional or data transactional based method, conversion to blockchain will be difficult and should be reconsidered. If data transactions are present then the next step is to determine what the various data transactions are that occur in the use case and how these transactions will be related to blockchain transactions in the proposed system.

Performance

Does the system require high (as in rapid millisecond) performance? Based on current developments, blockchain transactions take longer to process when compared to traditional databases or financial systems. That is, minutes, compared to milliseconds. Although different platforms offer different performance abilities (as will be discussed in the technology architecture), certain technology constraints result in blockchain being not a highly scalable system. These scalability matters are however expected to be resolved through time with increased research and development. If high information transaction speeds are a prerequisite then blockchain is not the ideal solution.

Workflow

Blockchain is a complex technology that has the ability to simplify difficult challenges such as supply chain tracking and tracing. The addition of blockchain should not complicate the supply chain. Thus the question has to be posed, '*would the blockchain simplify the workflow and supply chain processes?'*. Adding blockchain to a system that isn't designed around a central ledger would create architectural hurdles especially surrounding workflow.

If dis-separate systems have traditionally worked fine with one another without a blockchain, the addition of a blockchain can create friction that could lead to performance issues. Workflow must be evaluated for appropriate fit. If blockchain does not simplify workflow then it might not be the best choice of technology.

Operation

- Contractual relations and value exchange. The business must be dealing with value exchange or contractual exchange.

For blockchain to assist in reducing costs and delivering real business value, it is important that it looks at managing transactions around digital assets. If the application does not focus on managing contractual relationships and value exchange then a different technology could be more suited.

- Benefit from automation. Processes must benefit from automation.

Since blockchain can enable the use of smart contracts to automatically trigger transactions, it has potential to automate supply chain processes. Blockchain should be considered as a technology to automate many supply chain processes and the application in question should benefit from this automation. Specific processes that can be automated by blockchain should be identified.

- Desire to decentralize processes.

There must be a desire for the company or consortium to have certain processes, such as tracking and tracing, run in a decentralized manner. This is where a systems operation is distributed over a variety of actors instead of it being under control by one. If there is a need or company desire to solely operate or control the operation of the system then blockchain technology would not be best suited.

4.4.2 Supply Chain Stakeholders

Stakeholders

- Who are the different stakeholders in the supply chain?

Stakeholders are the different parties/companies that form part or are invested in the supply chain. As blockchain technology involves a network of participants, tracking and tracing using blockchain requires the co-operation and participation of these different stakeholders. These actors involved in a supply chain (who would possibly form part of the network) need to be identified and their role and participation defined.

- A consortium of partners need to be brought together to make important decisions regarding governance structure, incentives, platforms, consensus etc.

Blockchain allows for the sharing of data across a number of supply chain actors who might currently lack trust or other any other form of data sharing. In order to implement successfully, these parties need to be brought together to agree on various technical, organizational and legal matters regarding the blockchain such as: method of consensus, governance, operating structure, technology solution, ownership of IP and liability, many of which will be addressed later in the framework. The common thread between these partners is the shared value derived from the blockchain implementation. Rules and procedures will need to be established between stakeholders to resolve issues such as:

  - What data will be stored?
  - Who has rights to access the data?
  - How will new data be added?
  - Who gets to see what data?

When new data is added, it is validated using a consensus mechanism. This requires pre-agreed upon rules by all stakeholders in a legally binding contract. Additional decisions have to be made, such as the standardization of data (formats, entry, storage etc). This could mean adopting a new data standard or using an existing one. It is not needed to standardize all data but rather agree upon a small set of attributes that is required by all parties in the ecosystem.

- Are there enough stakeholders to ensure governance and security? Can each stakeholder run and be a part of the blockchain system?

The distribution of nodes in a blockchain network has numerous advantages, such as if one node fails you have enough others to continue support for the ecosystem. The more participants and distribution there is, the more secure the system becomes as it increases integrity and its ability to verify data. The questions that must be asked are:

  - Can the implementation manage and afford distribution of nodes and participants?
  - How many stakeholders are there in the ecosystem and can each stakeholder run nodes?
  - Does the scale of the distribution provide enough participants to achieve security, reliability etc?
  - Is there a risk that some stakeholders cannot be trusted?

Governance

In order to build a successful consortium, a governance structure is needed to drive the intended value and desired behaviour from all participants. Participants and businesses will have to adopt new structures of working in an ecosystem that shares data to realize its full benefits. This is devoid from the traditional structure where each entity owns their own system and relies on data from within its perimeter. Organizations need to change the way in which they approach ownership of data, systems and supply chain operations.

Trust

Blockchain can create trust in non-trustworthy environments such as in supply chain tracking and tracing. Providing the provenance of a product requires data visibility between actors in the supply chain. The key however is to ensure that this data is not only visible but trustworthy. The levels of trust between participants therefore have to be evaluated. If there are strong relations between actors in the supply chain with high levels of trust, does the supply chain really need to place its trust in a costly new technology?

As its often the case, even though different actors have varying levels of trust, this trust does not extend far along the chain. In large complex supply chains, a party cannot be expected to maintain trust with parties that are a few stages up or down from it in the supply chain. Blockchain has the capability to establish a network of trust between many different parties, some whom have no direct relations with each other. Blockchain can also remove the need for an ecosystem to trust a 3rd party, a key ability for certain applications. Thus the current levels of trust between participants have to be evaluated. Are they low enough to justify a blockchain solution?

The questions to be asked are:

- What is the current level of trust between stakeholders?
- How far up or down does this trust extend?
- Establish areas where trust must be improved.
- Do supply chain participants ask questions such as:
    - How can I verify that a certain event happened?
    - How can I trust the provenance of this item?

Interest and Incentives

- Are the contributors' incentives well aligned?

Tracking and tracing using blockchain technology is a costly initiative and requires largescale change management and digitalization across the supply chain. As many different stakeholders are involved, they all need to benefit from their investment and involvement in order to drive success. There needs to be an alignment of interests between the different stakeholders, businesses and organizations involved. There must be sufficient advances in efficiency and performance measures for each stakeholder. Blockchain has the potential to unlock significant value for different parties involved in the supply chain if it is designed and operated with the right incentives in mind. There must be sufficient incentives for organizations to change and offer performance and operating improvements on how the system operate today. Even though some stakeholders in the network might be competitors or have no direct business relation, if a common thread of value can be found such as the tracking and tracing of products or knowing the exact origins and nature of the product for example, it strongly supports the case for blockchain.

4.4.2.1 3rd Parties

- Who are the 3rd parties involved in the supply chain network?
- Will the role of 3rd parties be removed, reinvented or unaltered by blockchain?

Supply chain networks often use trusted 3rd parties to facilitate trust. Blockchain is a disruptive technology and can in some cases make the function of these 3rd parties obsolete. There are some important considerations to be made regarding 3rd parties. For blockchain to be a suitable solution, the scenario where different supply chain actors would not be able to place their trust in a 3rd party, must be met. If a trusted 3rd party can successfully fulfil the role that blockchain is intending to offer, then it is not the best use case for the technology. If there are specific requirements to use 3rd parties for verification of data for instance, then it might complicate the deployment of blockchain. The lack of 3rd parties along with a need for trusted intermediary or system strengthens the case for blockchain.

4.5 Technology architecture

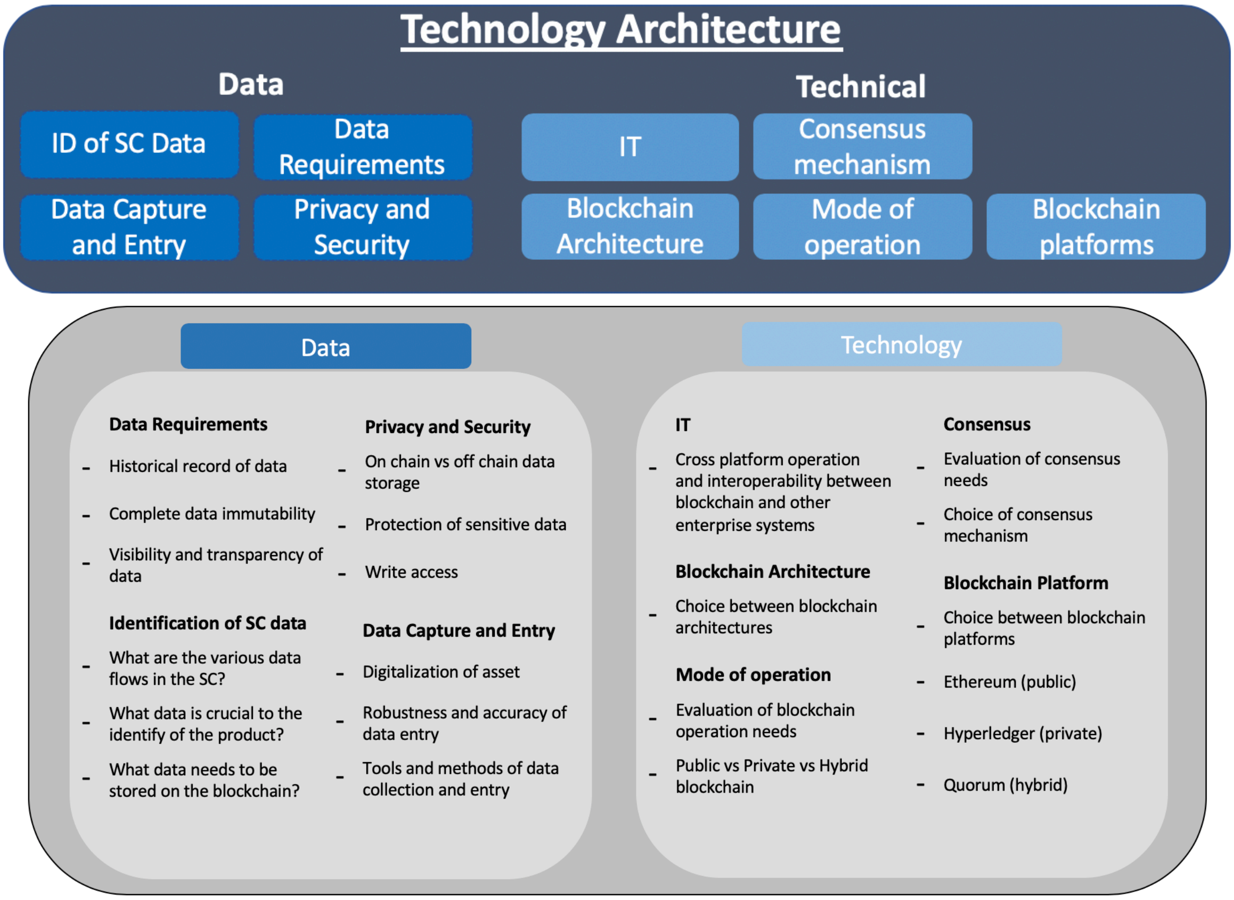


Figure 4-7 Expanded view of the technology architecture

The technology architecture section is a key component in the design of a blockchain. When considering a blockchain technology implementation, there are a variety of different design decisions to be made regarding the type of technology architecture, platform, governance or storage of data, to name a few.

As this technology is relatively new there is no clear formula for which type of blockchain configuration is the most suitable to use. Instead, there are a variety of different configurations being developed and used in applications around the world. This results in many different technology design decisions that need to be made which is highlighted in this section. The expanded view of the technology architecture section is shown in figure 4-7 The decisions are grouped into two collective areas, those involving the use of data in the supply chain and those involving the more technical blockchain related decisions.

4.5.1 Data

At the heart of the blockchain supply chain implementation is the availability of data. As products move through a supply chain there are various information transactions that occur and would be used in the tracking and tracing process. Information has to be transferred from the physical supply chain processes to the blockchain online. Thus, there are a few guidelines and considerations that need to be evaluated before the design of such a solution.

Data requirements

When data is stored on a blockchain it cannot be changed or deleted. It will be permanently recorded and visible to all. The use case in question needs to be able to harness these characteristics in order to be successful. It must first be considered if a permanent digital record of the asset can be created. Secondly, they must ask if the implementation will need to edit or delete data after uploading. If the answer to this question is yes, then blockchain is not the best suited technology for the case. Table 4-3 provides a summary of these requirements.

Table 4-3 Requirements of supply chain data

Historical record	Blockchain provides a complete historical record of data for an asset or product throughout its supply chain life cycle
Complete immutability	This data cannot be edited, updated or deleted in any way once it has been stored on the blockchain
Visibility and transparency	The data will be visible to all actors or parties that take part in the blockchain network

Identification of supply chain data

Table 4-4 Identification of supply chain data guidelines

Identify the various data flows in the supply chain	The first step is to identify the what data is stored in relation to the product. What data is transferred with the product as it moves up the supply chain? What are the different formats used to store this data and what is the nature of the data at various stages in the supply chain?
Identify what data is crucial to the identity of the product in question.	For a product to be tracked, a digital identify of it must be created. For the digital identify, there needs to be a key set of data that accurately identifies the product by its nature, state and location. The key is to identify what are the pieces of data needed in order be able to track and trace it through the supply chain.

Determine what data needs to be stored on the blockchain	Not all data needs to be stored on the blockchain as that would result in inefficiencies. Thus, the necessary pieces of information needed, needs to be identified. These are the key elements which will be stored on the chain by each party in order to track and trace the product

Data capture

In order to track and trace a product on the blockchain, the physical product first needs to be digitized. This means that the relevant data surrounding its nature and location needs to be captured and entered onto the blockchain. This process is very important as once data is uploaded there is no way of deleting or changing that data. Thus, accuracy and robustness of data capture and entry is important.

Although blockchain facilitates greater transparency and data security, it cannot ensure correct data entry. Thus, methods and tools have to be applied to reduce the risk of incorrect data entry and ensure information accuracy. There is an increasing trend to move towards more automated data collection and entry methods using tools and technologies such as:

- Product tagging using RFID, barcode or embedded NFC chips
- QR codes
- GPS tracking devices
- IOT devices (scanners, sensors, cameras etc.)
- Smart packaging and digital labelling
- Tamper evident seals and stickers
- Other identify management tools

Privacy, security and data management

The challenge is: for a blockchain tracking and tracing system to work, data needs to be shared between different companies/stakeholders/actors along the supply chain. However, these companies might not want sensitive data on their food commodities or internal operations to be shared. Thus, a decision needs to be made regarding what data needs to be stored on the blockchain and what needs to be kept off chain. It is not advisable to store large amounts of data on the blockchain due to scalability concerns.

Control also needs to be decided over which of the stakeholders will be able to upload data to the network. If the use case desires a network where write access is limited to a few key actors then blockchain is not the most suited technology for the case. This would centralize data upload and verification which is counterintuitive to blockchains' core principles

4.5.2 Technology

This section of the framework deals with the blockchain technology itself. It describes the various decisions and considerations that need to be made regarding the choice of technology. It discusses the different platforms, modes of operation, architectures and consensus mechanisms amongst others.

IT

For a digital tracking and tracing solution to be adopted by every actor in the supply chain ecosystem, ease of use is essential to encourage adoption. As each actor uses digital tools and platforms for tasks such as data collection and entry, inventory management, logistics, warehousing etc., it is essential that a blockchain solution should be able to integrate and work with other digital systems. The user experience should be considered at each level. Interoperability between the blockchain and other enterprise systems across a diverse range of actors in the supply chain, is crucial.

Public vs private blockchain

A decision has to be made regarding the mode of operation of the blockchain. The decision is either to use a public or private blockchain, or in some cases a combination of both. The different modes of operation have different performance characteristics and concerns factors such as who is allowed to write data, view transactions and participate in the network. Each has their own advantages and disadvantages and thus their use depends on the requirements needed by the application in question. The different modes of operation along with their characteristics are described below.

<u>Public</u>

Public blockchains are open and allows anyone to access and validate the integrity of the ledger. They are completely decentralized and secure as data cannot be changed once written to it. Anyone with permission can write data to nodes and anyone without permission can read data. A consensus mechanism is used to determine the current state of the ledger. Popular public blockchains include platforms such as Bitcoin and Ethereum. Figure 4-8 shows a representation of a public ledger where the network is open and visible to all (Kapoor, 2019). Specific characteristics are:

- Public and open transactions.
- Provides best blockchain benefits.
- Transparent, decentralized and immutable.
- No regulation on who joins the network.
- Slow transaction speed.
- Poor data privacy.
- Lack of governance.
- Can’t store large amounts of data.
- Low performance when compared to private.
- Highly scalable.

<u>Private</u>

In a private ledger, restrictions are placed on who is allowed to be part of the network and who can make changes and see transactions. The participants in the network are known and selected beforehand and only they can write and read transactions. There are varying degrees of private ledgers ranging from those that are almost centralized in their control to those that have a mixture of public and private functionality. Popular private ledgers include the Hyperledger blockchain designed and operated by IBM and Linux. Figure 4-8 shows a representation of a private ledger. (Kapoor, 2019). Common characteristics of public ledgers are:

- Network participants are known and selected.
- More centralized.
- Less decentralization benefits when compared to public.
- Has a strong governance system.
- Increased control over data privacy and management.
- Higher performance when compared to public.
- Faster and cheaper.
- Low scalability.
- Efficient.
- Can store larger amounts of data.

Choosing between public vs private

There are various considerations to be made when choosing between a public and private blockchain:

- If the stakeholders need the ability to change the functionality of the blockchain network (node distribution, permissioning, engagement, rules etc.) without having a long detailed discussion across the large open source blockchain forums, then a private/permissioned blockchain would be better.
- Also, if privacy is a concern to some companies who might not want to reveal information about processes to competitors then a private/permissioned blockchain is more suitable.
- Public blockchains have strong trust and data validation but lacks poor data privacy, has low throughput and lacks strong governance.
- In a public blockchain there is an economic incentive to follow the rules (miners adding new blocks and cryptocurrency payments) even though none of the nodes know or trust one another.
- Using a public blockchain results in better information transparency and auditability, but sacrifices performance and has a different cost model. In a public blockchain, data privacy relies on encryption or cryptographic hashes.
- By contrast in a private ledger, there is no payment for following the rules, instead there is a sense of accountability due to the visibility created (the nodes know who each other are and are held accountable) By removing the need for mining, data processing, transaction speeds and data storage performance dramatically increase.
- In a public chain, a new version of block is considered final when it is validated by a certain number of peers. That limits the size of blocks, as blocks storing larger data would take more time to spread. When blocks are added by fewer known entities (private), they can hold more data without slowing speeds down. Regarding privacy, you are still revealing data to the network but shielding it from the unauthorized public at large. This can enable an ecosystem of transparency over a supply chain without having people from the outside see transactions related to food shipments for example.
- Permissioned ledgers solve the problem of governance, there can be a governing body in charge to make decisions regarding consensus mechanism, rights, members etc.
- Public blockchains are a tremendous improvement on traditional databases if the things you worry about most are censorship and universal access. Under those circumstances, it might be a technology that sacrifices cost, speed, privacy, and predictability. If these sacrifices do not fit the business model of the supply chain, then a more limited private version would be better suited to the desired needs.
- Private/permissioned blockchains keep some of the benefits of open public blockchains, but you know who the network participants are. The degree of openness varies and can be defined by a set of controls.

Hybrid/permissioned

Information exchange, using a completely private or public ledger architecture might not be able to address the requirements in a supply chain scenario (Wu , et al., 2017). A solution based on both types can be more appropriate. Sensitive data can be stored in a private ledger, whilst information requiring high trust can be stored in a public ledger. The two types of ledgers can be designed to limit the information accessible by each stakeholder without reliance on central governance. These hybrid ledgers are usually based on the public Ethereum platform with some additional modifications to allow better control of privacy

In hybrid ledgers, some transactions that contain data sensitive to a company's operation can be protected whilst the data important for visibility and traceability can be open and shared for validation. In a tracking and tracing example, sensitive information such as when and how much produce a stakeholder receives could remain protected whilst data such as the nature and origin of the produce, which is important for supply chain visibility, can be stored in open to ensure tracking and tracing validity.

Enterprises, especially in the supply chain industry, are expected to adopt hybrid ledgers for their supply chains as they retain some benefits of a public blockchain whilst allowing some controls over privacy. Figure 4-8 below highlights some of the differences between public, private and hybrid blockchain (Kapoor, 2019).

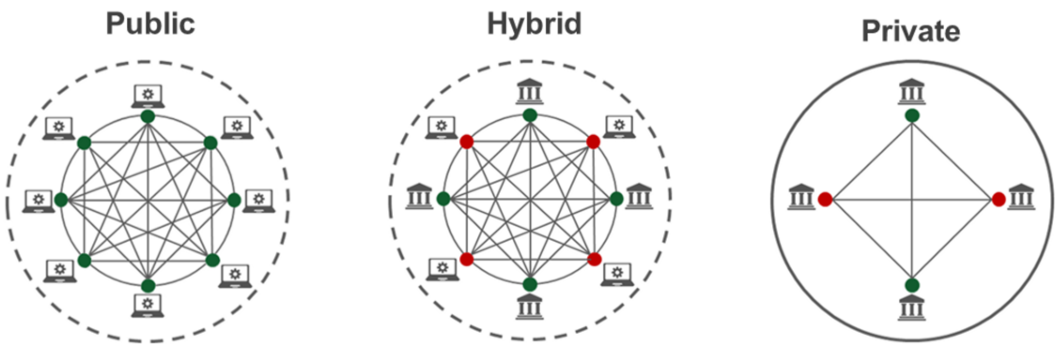


Figure 4-8 Comparison between public, hybrid and private structures

Further comparison between public, private and hybrid blockchains

The table 4-5 below provides a comparison between public, private and hybrid blockchain networks. It serves as a guide for supply chain professionals to help understand the performance differences between these networks in order to make enlightened decisions.

Table 4-5 Characteristics and properties of public, hybrid & private blockchains

		Public	**Hybrid**	**Private**
Characteristics	Cost/transaction	high	medium	low
	Performance	low	medium	high
	Trust	high	medium	low
	Scalability	high	medium	low
	Maintenance	low	high	medium
	Openness	high	medium	low
	Efficiency	low	high	high

		Public	Hybrid	Private
Properties	Centralized	No	Partial	Yes
	Consensus process	Permissionless	Permissioned	permissioned
	Immutability	Almost impossible to tamper with	Could be tampered	Possibility of tampering
	Consensus determination	All Miners	Select set of nodes	One organization
	Read permission	Public	Public or restricted	Public or restricted
	Cost efficiency	Low	Medium/neutral	high
	Flexibility/adaptability	low	medium	high
	Fundamental properties	high	medium	low

Blockchain platform

The decision has to be made on which blockchain platform to choose. There are different platforms with different architectures, consensus mechanisms, privacy and governance mechanisms, each with their own advantages and disadvantages. The platform chosen will be based on the needs of the stakeholders regarding privacy, governance, control and the desired outcomes expected from the tracking and tracing use case. There are currently two main platforms of choice regarding supply chain applications. Ethereum, which is a public blockchain with an added layer of smart contracts and business functionalities, and Hyperledger which is a private blockchain developed by big corporations such as IBM and the Linux foundation. There is also a hybrid platform named Quorum which is based on Ethereum but with added privacy features.

Use cases have to first question:

- What level of privacy, control and governance do they need in the blockchain network?
- What transactions need to be private and which ones must be open and visible?
- What are the performance requirements needed?
- The desired level of customization, maintenance and support. Will a generic platform work or would it have to have specific controls?

<u>Hyperledger (private)</u>

Hyperledger is a private blockchain supported by IBM and Linux. It has a very modular/extendable architecture that can be customized for a variety of different cases. Advantages of Hyperledger are that its development is closely tied to industry with companies such as IBM, Microsoft, Mastercard, SAP, Cisco, Intel, JP Morgan, Oracle and many others that are part of the Hyperledger community. This means that if companies in the supply chain network already use systems and services from those companies will likely have better blockchain integration with their systems. Also if a company is already using software services from one supplier then they are likely to use that same supplier if they are offering a blockchain solution. Hyperledger's development is driven by industry use cases.

<u>Ethereum (public)</u>

Ethereum is a public blockchain with smart contract functionality. It was developed as an alternative to the bitcoin blockchain, but with an added layer of business functions and mechanisms making it more useful for blockchain use cases. Compared to Hyperledger which is very modular and use case driven. Ethereum is more inclined to being a generic platform that can be used for different applications.

Quorum (hybrid)

Quorum is based on the Ethereum platform but has more controls over privacy and improved performance. In the Quorum blockchain, some transactions containing sensitive data can be encrypted and protected, whilst other transactions can be open and visible. Quorum was developed to retain the advantages from Ethereum but adding appeal to applications requiring more privacy controls such as in tracking and tracing. The higher performance of the platform also benefits scalability in industry. The following table serves to provide a more in depth comparison between different platforms used for blockchain supply chain track and trace cases.

Table 4-6 Comparison between blockchain platforms

Characteristic	**Platform**				
	Ethereum Based		**Hyperledger**		**Bitcoin**
	Ethereum	Quorum	Fabric	Sawtooth	Bitcoin
Description	Generic blockchain platform	Privacy & performance enhanced Ethereum blockchain	Modular blockchain platform	Highly modular and versatile blockchain platform	Decentralized peer to peer cryptocurrency network
Mode of operation	Permissionless Public	Permissioned private/hybrid	Permissioned private	Private	Permissionless public
Consensus	Proof-of-work based mining	Raft-Based, Istanbul BFT, voting based	Multiple approaches possible	Multiple approaches possible	Proof-of-work
Smart contracts	Smart-contract code(e.g. solidarity)	Private smart contracts	Smart-contract code(e.g. Java, Go)	Smart contract abstraction	None
Currency	Ether/tokens via smart contract	N/A	None	None	Bitcoin

Consensus mechanisms

The consensus mechanism is the method used by the blockchain to authenticate and validate a transaction without the need for a central authority. It is the way in which the integrity of the ledger is upheld between a network of trusted or untrusted individuals and is central to the functioning of the blockchain. The choice of consensus mechanisms will be influenced by the choice of platform and mode of operation. It impacts security and scalability. There are many different consensus mechanisms with different rules on how to achieve consensus between individuals. They differ in computational power required, performance, transaction speed and security. Generally consensus requires mining, however there are other mechanisms being developed that do not require mining and are less resource intensive but less proven. Security level is often defined by the least percent of malicious nodes in the network. The tables below summarize some traditional consensus mechanisms (4-7) and their performance characteristics (4-8) (Xu, et al., 2017). The table 4-9 depicts different elements that need to be considered in the evaluation of these mechanisms, adopted from (KPMG, 2016).

Table 4-7 Overview of important consensus mechanisms

Mechanism	Uses	Description
POW (Proof of Work)	Bitcoin, Ethereum (changing to POS)	Uses mining in which nodes compete to validate the generation of the next block by solving mathematical challenges. First node to solve the block is rewarded and the block is verified by the network. Generates consensus among untrusted individuals yet is resource intensive.
POS (Proof of Stake)	Ethereum (soon to be)	POS forgoes the computational challenge, but offers a randomly selected subset of node the opportunity to produce each block. The probability of selection is weighed by the node's investment in the system, quantified by the value or duration of asset holdings. More cost efficient and less computationally intensive.
BGFT (byzantine general fault tolerance)	Hyperledger Fabric	Roughly speaking, BFT-based blockchains offers a much stronger consistency guarantee and lower latency, but for a smaller number of participants.
POET (Proof of Elapsed Time)	Hyperledger Sawtooth	Mechanism that consumes far less resources that POW. It prevents high resource utilization and high energy consumption and keeps the process more efficient by following a fair lottery system.
Raft and Istanbul BGFT	Quorum	Raft based is very fast and efficient at storage. It offers transaction finality but does not have the best protection against bad actors when compared to Istanbul BGFT. Istanbul is more secure and hard to tamper with but lacks efficiency and does not manage storage of data as well as Raft.
DPOS (Delegated Proof of Stake)	Newer platforms such as EOS.	DPOS speeds up transaction and block creation without compromising the decentralization incentive. It offers a more efficient variation on the Proof-of-Stake mechanism. Users vote to select witnesses and those who get the most votes validates transactions. Users can delegate voting power to others whom they trust. It is much faster and more efficient than POW and POS whilst still being secure.

Table 4-8 Comparison of consensus mechanisms

	POW	POS	BFT
Cost efficiency	low	medium	high
Performance	low	medium	high
Flexibility	low	high	low
Fundamental properties	high	medium	low

Table 4-9 Key criteria for consensus mechanism evaluation

Evaluation of consensus mechanisms	
Key topic	**Key considerations**
Overall consensus methodology	Ownership of nodes, no nodes needed to validate a transaction, fault tolerance, data storage
Governance, risks, and control	Enforcement of governance/controls, Responsibilities and legal action, access control and admin privileges, risk mitigation, counterparty risk
Performance	Time to validate transactions, Volume and value, scalability, number of fields per transaction, speed, synchronization
Security	Transaction activity monitoring, digital signatures, security testing and certifications, infrastructure hosting options and security architecture, documentation, network synchronisation
Privacy	Verifiable authenticity, transparency and visibility into transactions, data encryption
Cryptography strength of algorithm	Key generation and lifecycle error monitoring, system strictness, library and hsm integration
Tokenization (if used)	Asset token and lifecycle, use of tokens, transaction signing, token security
Implementation approach	Use cases explored, cost and time to implement, business case, working partners.

Architecture models

Central hub and spoke

Market leader centric structure. A central entity or company would lead the effort in designing, implementing and operating a blockchain on the supply chain system. Adopted by many initial supply chain pilots which is primarily led by a single organization with several suppliers along the supply chain.

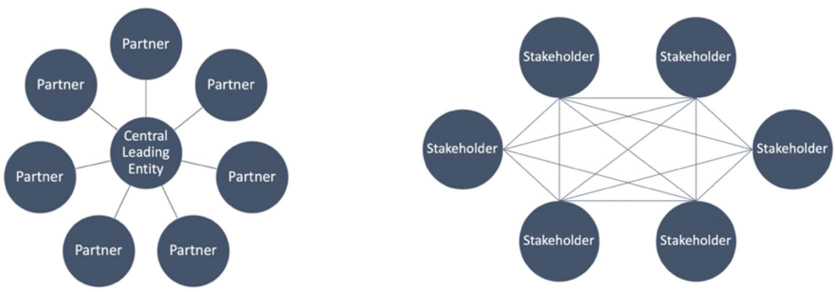


Figure 4-9 Central hub and spoke (left), consortium peers (right)

Consortium peers' model

In a consortium peers model, different stakeholders (producers, suppliers, regulators, governments etc.) agree to form a consortium to build a blockchain supply chain ecosystem that they are all involved in and use. Each participant has their own incentive to participate. This model is more complex than the hub in spoke in terms of governance and adoption however the outcome can be more transformational as it considers the wider ecosystem of stakeholders both vertically and horizontally.

Platform install base converted to network

In this model an existing platform is converted into a blockchain network. This is where existing organizations, who already communicate with each other, connect through a blockchain network to increase efficiency.

Pairwise corporate use of blockchain

In this case there would be two companies making use of the same private blockchain. These companies would have processes that are heavily integrated with one another and regularly share transactions. Using a blockchain in this case will provide visibility and remove information asymmetries between them.

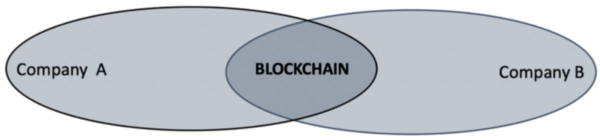


Figure 4-10 Pairwise configuration

Classic open and public

This public blockchain approach is similar to that of bitcoin. In this architecture all firms, persons, companies would be allowed to join and their transactions would be publicly visible. Making information public such as tracking and tracing of goods or provenance of items can remove any information asymmetries and increase transparency. However this approach has its limitations as it makes it possible for competitors or malicious actors to access information that might be to a disadvantage to the companies involved.

Multiple consortium

Multiple companies all using the same private blockchain. In this architecture, multiple companies are using the same blockchain to capture a particular type of transaction exchange that each of the different companies are involved in. It is similar to the central hub and spoke architecture especially when a large market leader company is heading the blockchain implementation. To control privacy and business intelligence of the individual companies involved, the platform can offer different views to each party. In this way some parties can be restricted from viewing sensitive information from a potential competitor whilst still working on the same blockchain network.

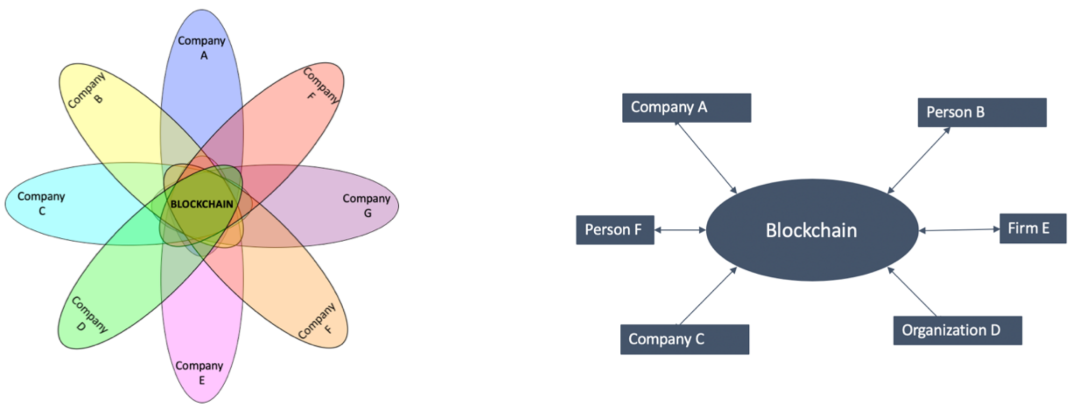


Figure 4-11 Multiple consortium (left), open and public (right)

4.6 Feasibility

This section presents the key questions that must be asked in order to determine whether the given use case is feasible for blockchain adoption. The answers to the questions will either lead towards the adoption of blockchain or away from it. One of the biggest problems that was highlighted in the literature review, as well as the industry examples is, was determining whether the use of blockchain is justified. By having a tool that can aid this process will help prevent the possibility of wasting resources and aid in streamlining the selection of feasible use cases. Figure 4-12 provides an expanded view of this sub-architecture and table 4-10 describes it in more detail.

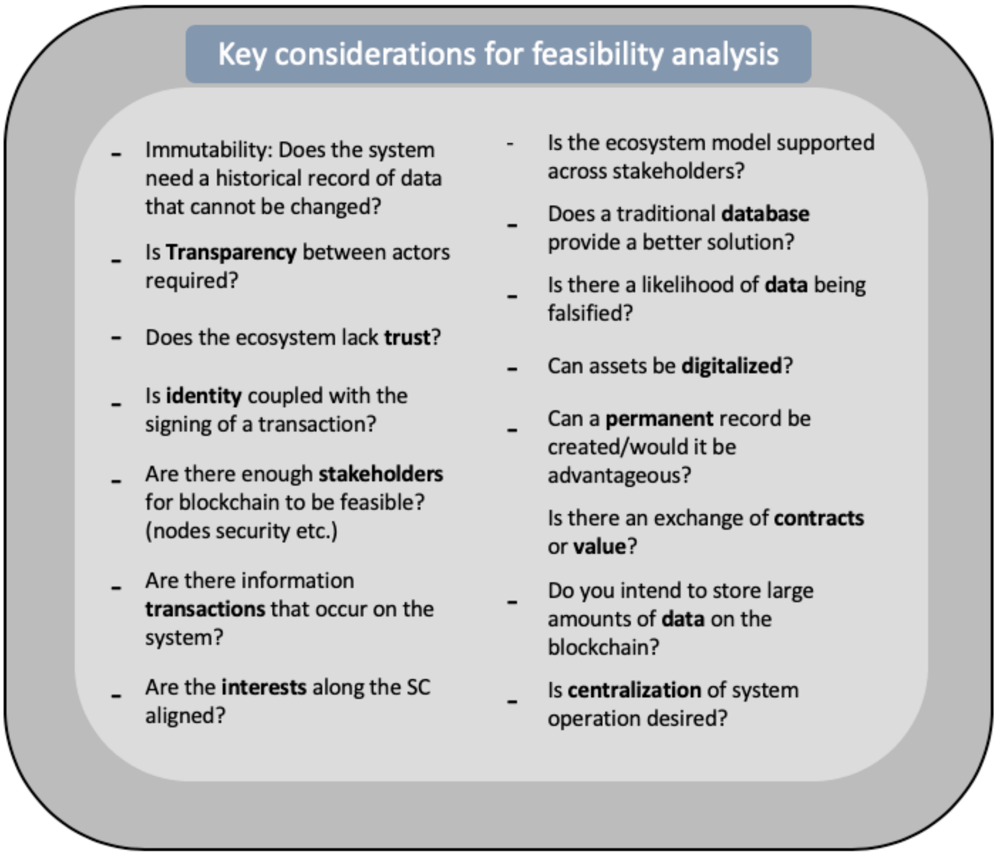


Figure 4-12 Expanded view of feasibility sub-architecture

Table 4-10 Overview and explanation of the feasibility sub-architecture

Explanation of feasibility architecture's key considerations	
Key Consideration	Brief explanation
Immutability: Does the system need a historical record of data that cannot be changed?	The main advantages of blockchain is it provides an immutable record of data that can't be changed. If this is something that is not desired for a product or process then blockchain is not a applicable.

Is **Transparency** between actors required?	Does the supply chain network require certain processes or pieces of information to be transparent (such as product origin, certificates of standards, manufacturing methods etc)? When transparency of information is required between parties, it is a strong indicator for blockchain applicableness.
Does the ecosystem lack **trust**?	If supply chain parties trust one another, there is no real reason to use blockchain.
Is **identity** coupled with the signing of a transaction?	Systems in which particular individuals/actors or processes must be tied to transactions can benefit from blockchain. These are use cases in which there is a requirement to know the individual (human or company) or system involved in specific transactions.
Are there enough **stakeholders** for blockchain to be feasible? (nodes security etc.)	The larger the network decentralization, the more difficult it is for fraudulent nodes to manipulate transactions due to the larger cryptographic complexity. A system must be large enough in order for the benefits of blockchain to make sense.
Are there information **transactions** that occur on the system?	Blockchain is a type of information system that contains a record of transactions containing data. It is particularly good at providing a secure list of data transactions. If data transactions are not part of the use case, then it might not be relevant for that use case to consider blockchain technology.
Are the **interests** along the SC aligned?	Each member in the supply chain would have to be invested in a blockchain solution. It is important for their interests to be aligned, otherwise some members would not have a need or see the use to be part of it. This will make deployment and achieving governance a problem.
Is the ecosystem model supported across stakeholders?	Blockchains are critical for creating supply chain ecosystems. If the vision or strategy of the company is to create a supply chain ecosystem across multiple nodes then it is a strong indicator for the use of blockchain.
Does a traditional **database** provide a better solution?	Blockchains are complicated and expensive to deploy as of 2019. If the particular use case sees no direct advantage for a blockchain over a traditional solution then there is no need to use the technology.
Is there a likelihood of **data** being falsified?	One of the main reasons to use blockchain is to produce an immutable secure record that cannot be changed. If there is no likelihood of false data being added in a traditional solution then it provides no argument why a blockchain would be necessary.
Can assets be **digitalized**?	An assets identity needs to be able to be represented digitally in order for it to be tracked through blockchain.
Can a **permanent** record be created/would it be advantageous?	The use case in question needs to benefit from the fact that there is a permanent record of transactions, assets, products etc. that can be accessed.
Is there an exchange of **contracts** or **value**?	Blockchain is useful for managing the exchange of value or information contracts.

Do you intend to store large amounts of **data** on the blockchain?	Blockchain in general is not well adapted for the storage of large amounts of data on the chain as it has to be replicated and validated across a large network. Thus, use cases have to question what data is key to the blockchain. Different platforms have different data handling abilities. Some newer platforms and consensus mechanisms have been modified so that they can store large amounts of data whilst still offering performance. This comes with trade-offs thus this question has to be seriously considered.
Is **centralization** of system operation desired?	Companies that are considering blockchain but still wish to have some sort of majority control over the network and use of data are defeating the purpose of having blockchain in the first place. Blockchains advantages are realized when control over the network is decentralized.

4.7 Chapter summary

This chapter presented the design reference architecture, aimed at guiding teams and companies on the design of blockchain track and trace solutions in the supply chain. Figure 4-2 showcases the overall architecture with the detailed sub-architectures and guidelines. The sub-chapters that follow evaluated each guideline in detail. In the following chapter, the validity and applicableness of the architecture will be demonstrated. The first part will comprise of a case study analysis followed by the architecture evaluation through interviews with industry experts.

Chapter 5
DRA Validation: FMCG Supply Chain Case Study & Expert Analysis

In the previous chapter, a Design Reference Architecture for the development of tracking and tracing solutions in the supply chain using blockchain technology, was developed and explained. The next step deals with the validation of the architecture. A two part method will be used in the validation of the design reference architecture. Firstly, aided by a case study analysis, the architecture will be used to help guide the development of a supply chain tracking and tracing blockchain case study. This aims to test the real world practicality of the architecture. In the second, semi structured interviews with industry experts will be used. Experts will examine the architecture and provide feedback based on its validity and usefulness.

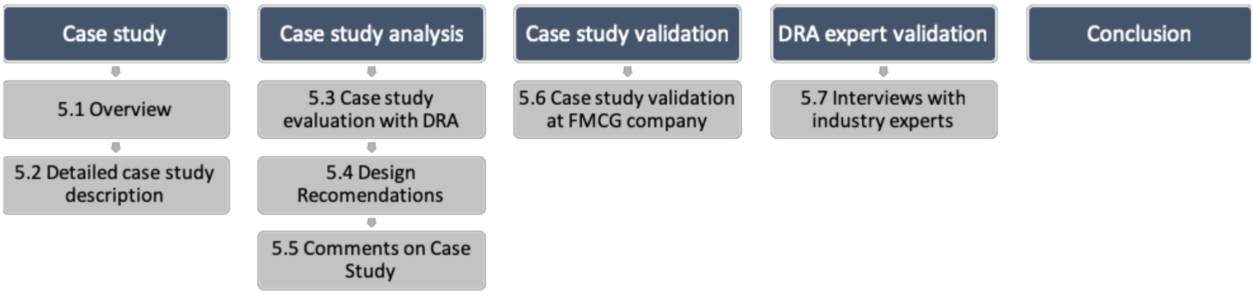


Figure 5-1 Chapter overview

5.1 Overview of case study procedure

The case study will involve a supply chain company that is considering the application of blockchain technology for tracking and tracing of products. The DRA will be used to analyse the case study and provide guidelines towards decisions that need to be made as well as test the feasibility of the project. Afterwards the generated results and observations will be presented to the company where they will be evaluated. The DRA should aid the supply chain company in the design phase/process of a blockchain based supply chain for increased visibility and traceability.

A case study was set up with one of the largest multinational FMCG supply chain companies in the world. Per ethical agreement the name of the company will not be mentioned. The company has considered blockchain technology to aid with supply chain visibility, transparency as swell as tracking and tracing. They have also included the technology into their digital supply chain strategy for the future. Their vision is to develop a blockchain solution for more complex supply chains to aid in providing provenance and transparency.

The company is in the process of setting up a pilot program to test the implementation of blockchain into one of their supply chains. A smaller, less complex, supply chain was chosen as that would provide the best proving ground to test the technology before applying it to larger more complex cases. They have granted permission for this pilot programme to be used as a case study in evaluation of the design reference architecture and have provided all relevant information requested. The case study involves the tracking and tracing of non genetically-modified maize as it moves from the farm, to be processed into FMCG products.

5.2 Case Study description: The Non-GMO Maize

5.2.1 Background on Non-GMO Maize

The Non-GMO Maize supply chain involves the cultivation of maize that is free from genetic modifications for use in a variety of FMCG products. In this case it is used for a specific foods product. There are two types of maize used in FMCG supply chains, the traditional genetically modified maize (GMO) and the specific maize that is free from genetic modifications (Non-GMO). GMO maize is genetically engineered to express agriculturally desirable traits, such as being resistant to pests, diseases or environmental conditions.

Even though GMO maize is more desirable and produces higher yields, there is still a big demand for non-GMO maize. Fears over the uncertain future implications of genetically modified organisms and the desire for produce that is 100% natural, drives the demand for non-GMO products. It is thus essential for the supply chain to be able to ensure that certain products are in fact non-GMO and there are strict measures in place to guarantee this assurance.

Figure 5-2 Example of a non-GMO foods logo

In this way the non-GMO maize supply chain differs to that of the traditional maize supply chain as there are various checks and processes to help track and trace this specific characteristic from the farm to the retailer. Every supply chain actor has a vested interest in tracking this characteristic as non-GMO maize can easily become contaminated by GMO maize and other ingredients in the supply chain. Contamination can result in health risks to the consumer, false advertising and loss of profit. There is thus a strong demand for the ability to track and trace this product in the supply chain.

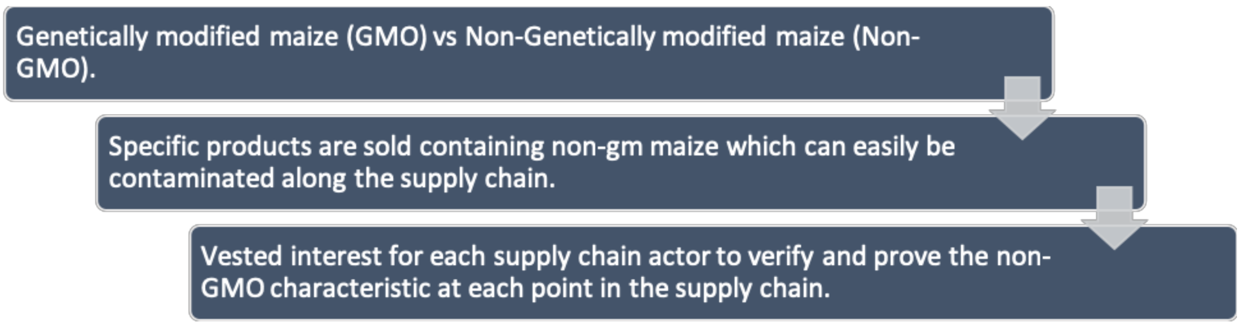


Figure 5-3 Overview of the non-GMO maize case

5.2.2 Case Study Problem Statement

Why is there a need for blockchain in this supply chain? This section will explain the problem background and motivation for the use of blockchain in this supply chain.

5.2.2.1 Problem background

The FMCG supply chain industry involves products from many different categories including packaged foods, beverages, home care and personal hygiene products. These are made up of ingredients that originate from around the world and are produced using a plethora of different methods. Among these are products with specific measurable characteristics that are important to both the value of the products, and other factors such as health, safety and the environment. These characteristics have to be assured by each company along the supply chain.

The assurance of these depend on information sharing between the different parties involved in the supply chain. Currently, in supply chains governed by the FMCG company, there is a mixture of paper-based and IT processes, much like the '*silo information model*' explained in chapter one and two. This hinders supply chain visibility and transparency, especially in some more complex supply chains. In the non-GMO maize supply chain, it is important for the FMCG company to verify that the ingredients it uses for their non-GMO products, in this case non-GMO maize, does not contain any traces of genetically modified maize. The utilization of paper-based certificate system limits visibility to 1st tier suppliers and results in long delays and administration issues if the product has to be traced elsewhere in the supply chain.

In other more complex supply chains, such as the palm oil supply chain, limited visibility between different parties makes it difficult to verify the provenance of palm oil. Palm oil is an ingredient that is included in many FMCG products, however its cultivation has been linked to severe deforestation. Companies therefore are under increasing pressure to source palm oil from areas where sustainable farming practices are practiced.

The benefits of blockchain technology with tracking and tracing has been identified as solutions to these problems. A system that stretches over the entire supply chain, creating an ecosystem of information sharing and transparency, would enable the company to verify the provenance of its products by tracking and tracing it across the supply chain. However, due to the geographic complexity and number of partners involved in supply chains, such as in the palm oil example, designing and deploying a blockchain solution will be risky, expensive and not strategic.

There is a lack of knowledge and real world results on how exactly blockchain will work in such a supply chain. This means that it would be costly and probably unsuccessful to fully deploy a developing technology to such a supply chain. The strategy that has been identified is to first test the technology on a smaller, less complex supply chain, in this case the non-GMO maize supply chain. This will provide an environment where data can be gathered experimented information can be generated. This information can then be applied to more complex supply chains once the correct deployment method and strategy has been understood from the smaller pilot study.

5.2.2.2 Problem definition

Tracking and tracing using blockchain, has been identified as a method to increase supply chain visibility in the non-GMO maize supply chain. The current method is a manual process using a mixture of paper-based and IT traceability. This results in limited visibility across the supply chain and long delays and administration of products that have to be tracked at certain stages. Due to the fact that non-GMO maize is easily contaminated and needs strict measures to insure its nature, verifying its characteristics at each stage of the supply chain from farm to retailer is of crucial importance. The case study aims to use blockchain technology to facilitate tracking and tracing of the non-GMO maize and its GMO state at each stage of the supply chain.

As blockchain technology is relatively new, especially with its use in supply chains, there is little real world information, research and guidance as to how to approach this endeavour. The FMCG company has stressed the need for a framework or architecture to help guide the implementation of this technology and to highlight the various decisions that have to be made.

The case study will thus by analysed using the design reference architecture in order to better guide the design of the blockchain track and trace solution. It will aim to provide general design guidelines, best practices and highlight the different decisions and considerations that have to be made.

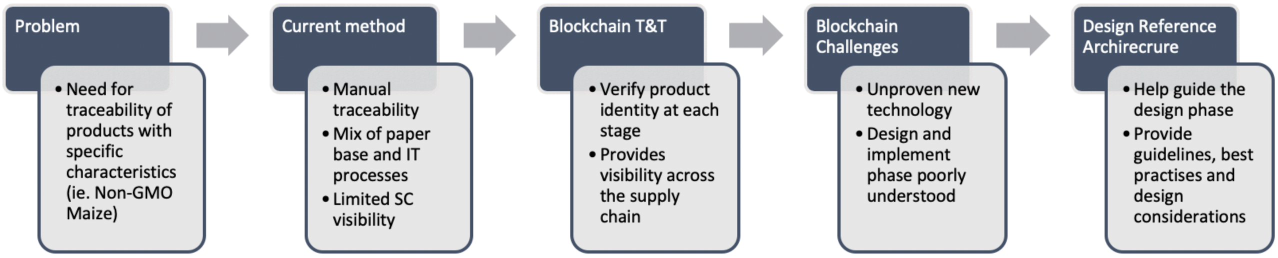


Figure 5-4 Case study problem description

5.2.3 Supply Chain analysis

Figure 5-5 and 5-6 provides an overview of the non-GMO supply chain along with a comparison to the traditional GMO supply chain. Farmers plant and cultivate special non-GMO seeds. Non-GMO maize has to be grown apart from traditional GMO maize to avoid any form of contamination. The maize is harvested on the farms and transported to the silo where it is stored in bulk. The silo can store maize harvested from multiple farms in the area. The maize is now transported to the mill where it is processed to a certain specification for use in food production. The processed maize is transported to the FMCG company where it is used as an ingredient in a variety of products. After the products are made, they are packaged and sent to the distributer who distributes it out to retailers where customers can purchase the product.

The non-GMO maize supply chain is much stricter and under more control than the GMO maize supply chain. The main risk is that GMO maize coming into contact with Non-GMO maize resulting in contamination. As contamination has severe implications, it is important that the final product is free from any GMO ingredient. To manage this, the Non-GMO maize supply chain is completely separated from traditional GMO Maize. The crops are grown on different fields and different transporters and containers are used in storage and transport. If any equipment is used to transport, process or store both GM and non-GM maize, it has to be thoroughly cleaned and pass inspections before switching between one another.

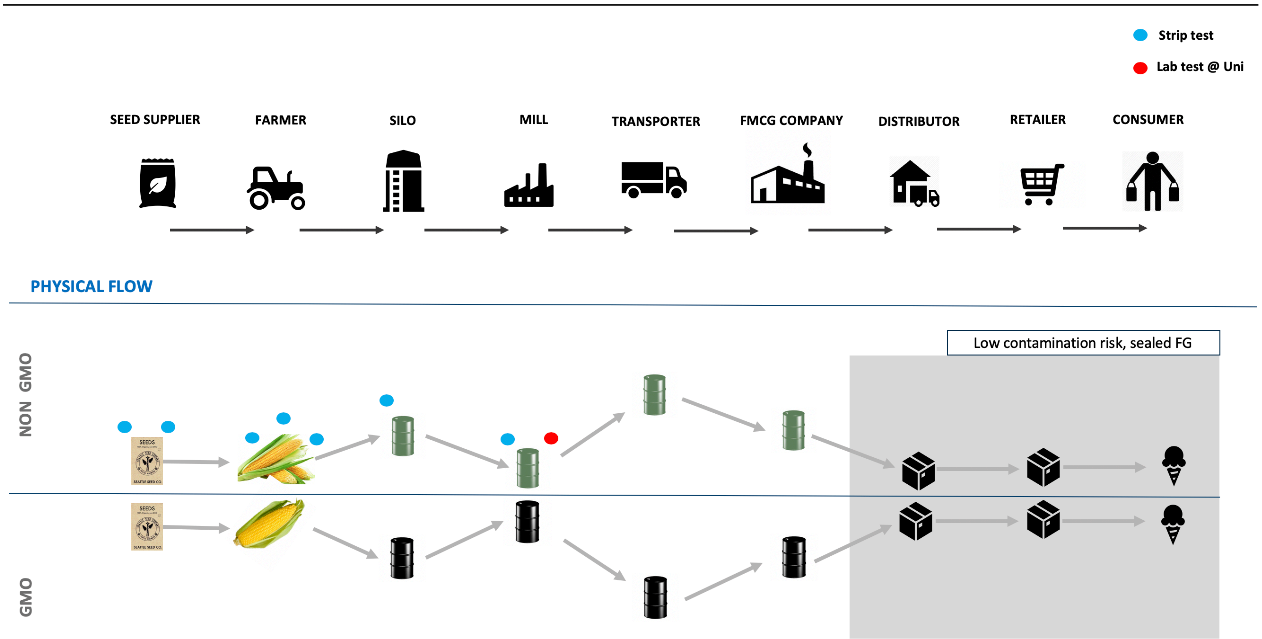


Figure 5-5 Physical flow of the non-GMO maize supply chain

In order guarantee that the produce at each stage is Non-GM and has not been contaminated, various tests are done at different stages of the supply chain. Samples of maize are taken and tested for any traces of genetically modified material in what is known as a strip test. If it contains GM material then the batch is considered contaminated. A strip test is done on the seeds and on the crop in the plantation by the farmer. Once harvested and transported to the silo, the silo does another strip test to validate that the maize is in fact Non-GM and has not been contaminated along the way. This process is repeated at the mill.

After the maize has been milled, it is no longer possible to conduct a strip test. The final test that can be done is to send samples of the milled particles to a university laboratory. After this stage it is not possible to determine whether the batches have been contaminated or not. These final results are sent to the FMCG company as a certainty that the delivery of maize from the mill is Non-GMO. The processes from this stage in the supply chain onwards are closed loop, meaning there is no chance that contamination can occur.

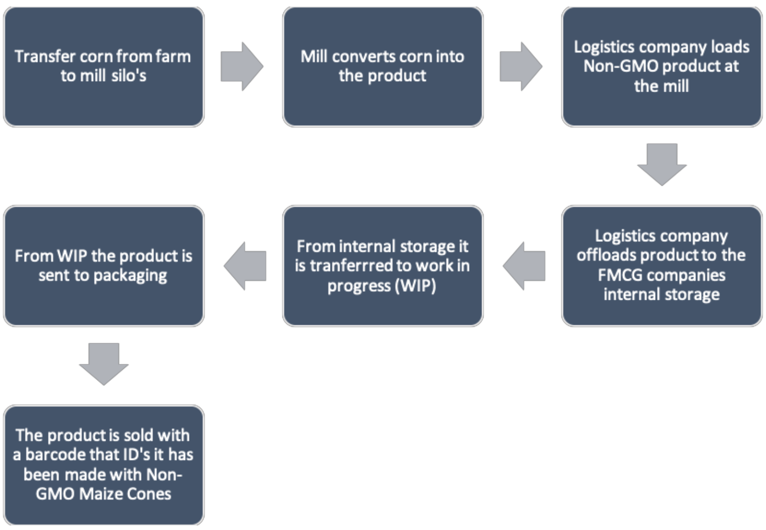


Figure 5-6 Overview of supply chain processes

5.2.4 Initial Scope

After evaluating the supply chain, it was decided (by the company) to focus the initial stage of the blockchain pilot only on a certain section of the supply chain. This section is the part stretching from the silo to the factory. In this area the company has increased control and communication and will make it easier to facilitate co-operation on the project between the different stakeholders involved.

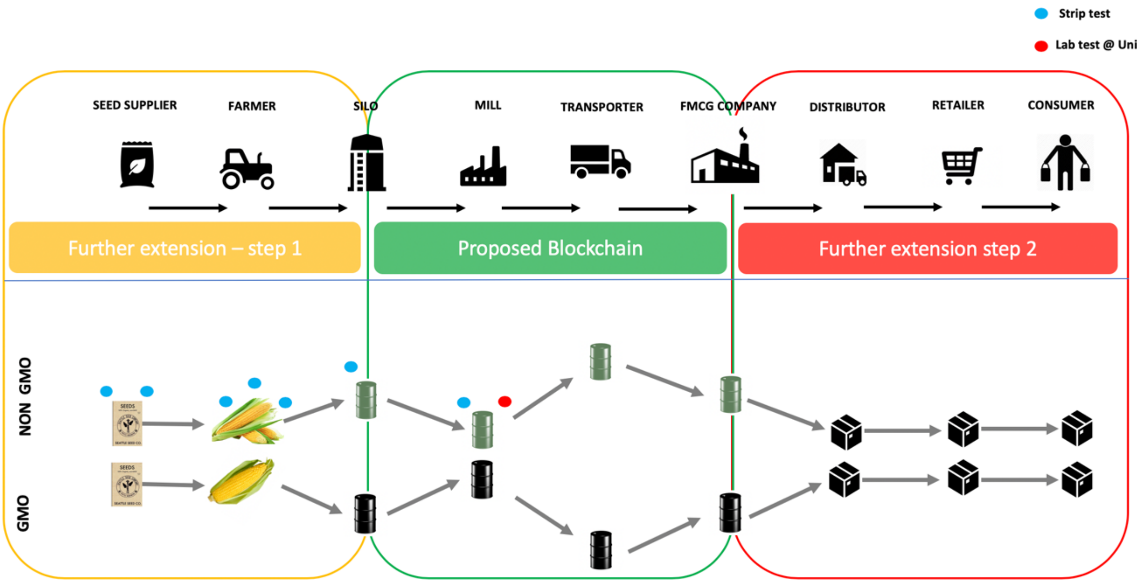


Figure 5-7 Scope of proposed blockchain implementation

The idea would be to initially implement blockchain in a small scale environment where there are less uncertainties and complexities that could influence the outcome of the project. By starting small, mistakes can be corrected and improvements made before involving the rest of the supply chain. Knowledge acquired from the initial stage will be transferred to the next stages of deployment as indicated in figure 5-7.

5.2.5 Motivation and reasoning behind the use of this case study

The non-GMO maize foods supply chain is a real world supply chain with an existing traceability system, consisting of a mixture of paper and IT based traceability. It handles a product with a specific characteristic which drives the need for transparency and provenance. The main motivations for using this supply chain as a case study for the DRA validation is presented in table 5-1 below.

Table 5-1 Motivation for the choice of case study

	Reasons for choosing the Non-GMO Maize supply chain
1.	It is already an established and fully functional supply chain.
2.	There is existing traceability within the supply chain (paper-based). This provides a basis for comparing the traditional method against the blockchain based traceability.
3.	There is a strong need for the raw material to be tracked to in order to confirm non-GMO status.

4. It is a very linear supply chain. There is a single supplier and a single factory which simplifies the supply chain network.
5. The small material volume makes it easy to run and manage pilot projects within this supply chain.

5.3 DRA Application to the Non-GMO Maize Supply Chain

In this section the case study is evaluated using the design reference architecture. Remarks on the case study will be given under each section of the design reference architecture. The end of this section will contain a summary.

5.3.1 Information flow mapping

In order to properly analyse the supply chain using the DRA, a complete information flow study of the supply chain had to be done. This was done by a company visit and using information collected through the case study. The supply chain was analysed to determine all flows of information that occurred at each location and also the verification procedures that were involved. Through this, a map could be generated showing all the relevant information connected to the maize as it moves between parties in the supply chain, as seen in figure 5-8 below.

The raw non-GMO maize is tested for its GMO status at the silo. When a shipment is sent to the mill, a transfer document is compiled which contains the information identifying that specific shipment batch. It contains the nature of the contents, batch weight, its origin and where its heading, the date of the shipment and date of arrival. This transfer document also contains the serial number that refers to a strip test certificate.

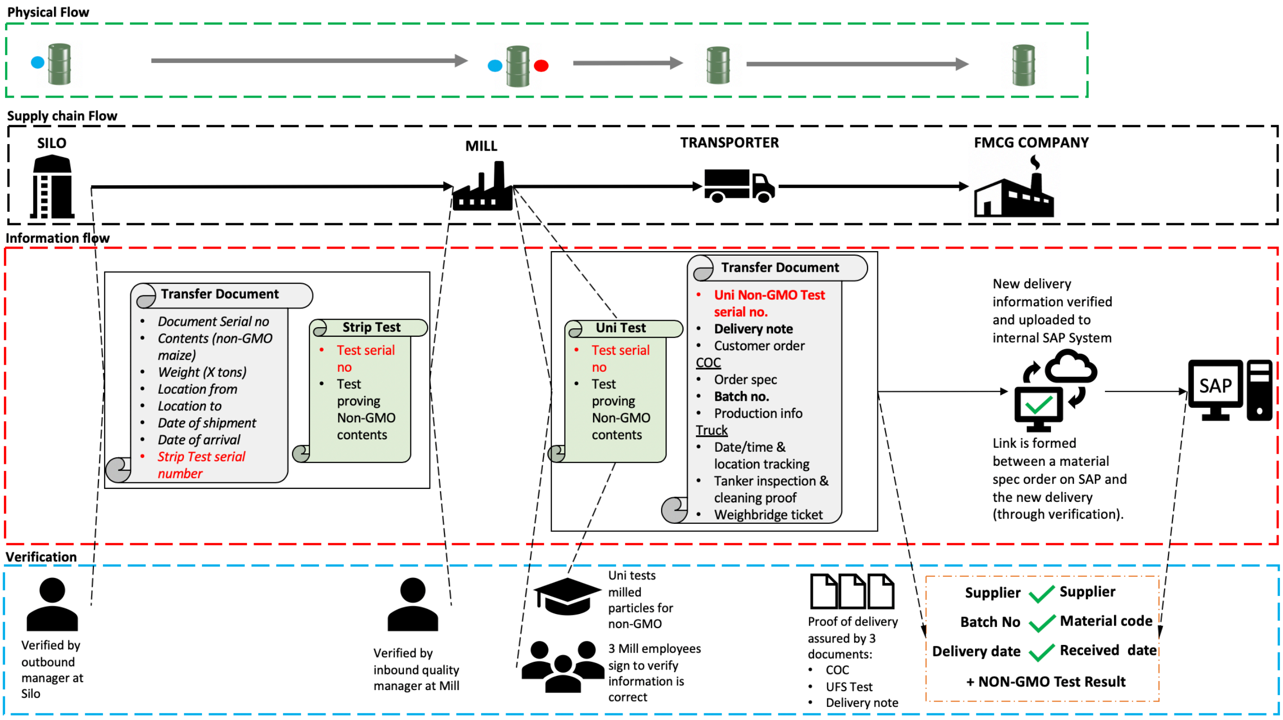


Figure 5-8 Information flow study of the non-GMO maize supply chain

This certificate is generated to show the results of the GMO contamination test to determine if the maize is non-GMO in nature and has not been contaminated. The transfer document and strip test both have a unique serial number that relates to the specific shipment. This information is verified by the outbound manager at the Silo.

As the shipment arrives at the mill, the transfer document and strip test certificate is verified by the inbound quality manager. At the mill, another strip test is done to certify that the maize has not been contaminated along the route. After the maize is processed, no more strip tests can be done. Thus, the last method used to certify its non-GMO status is by a special lab test at a partnering university, using samples. As the processed non-GMO maize gets ready to be shipped to the FMCG company, another transfer document is generated that includes information on the specifics of the order, batch number, production info etc. This insures the customer (FMCG company) that the material is of the spec ordered. In addition to this, the serial number of the last test at the university is included, which certifies the current batch is free from any GM material.

This document is passed on to the logistics company where information such as the truck location, date/time and tanker inspection records are added. When the shipment arrives at the FMCG company the proof of delivery is ensured by three documents containing: the supplier ID, batch number, delivery date and GMO test results. On the FMCG companies' side, this is matched with the order placed from the specific supplier, material code and received date. This information is uploaded into the companies SAP system. From this point onwards, the internal IT system tracks and traces the material as it is used within the company.

5.3.2 Strategic Intent Section

Digitalization

The FMCG companies' strategy should involve digitalization initiatives across the parties involved in the supply chain with the goal being digital information availability and transparency. The Silo, Mill and Logistics company should have the digital capabilities to partake in a blockchain network and require them to have the means to record, digitize and upload supply chain data. Thus, the overall blockchain strategy should include measuring the digital capability of each party and ensuring that it has the required enabling technologies to collect, digitize and upload data to the blockchain. It is often the case in supply chains that digital capability decreases as one moves down the supply chain, as is evident from this case.

It should be taken into account that for a blockchain implementation to be successful, it is expected that the system should be able to interact with existing information systems in the supply chain. As each party has its own method or system of managing information, the challenge would be to insure that blockchain will work with all of these systems. For example, the FMCG company uses a SAP system. It is not logical to expect that each party abandon their systems for a blockchain system. Instead, blockchain is expected to be a separate 'over and above' system that spans across the entire supply chain and ties into each party.

Leadership

Currently, the FMCG company has initiated this blockchain venture and is expected to spearhead or lead the initiative in this supply chain case. They thus have a responsibility in effectively communicating this project throughout the supply chain network in to achieve successful results. This blockchain project includes a host of different companies and stakeholders that form the producers and suppliers along the supply chain route. In the initial phase (upon which is focused), the project has to be co-ordinated between the Silo, Mill, Logistics service and of-course, the FMCG company. The FMCG company has to clarify the business case and benefits of blockchain to each of the stakeholders. This will necessitate a better understanding of the needs and challenges of each stakeholder. It is important that the advantages and benefits obtained by such a system for each stakeholder are clearly explained. In this case, it would add a transparent layer of trust with regards to the tested non-GMO status of the maize at each point in the supply chain.

Leadership activities that have been completed:

- The need identified is the tracking of Non-GMO status of maize for better supply chain visibility and transparency.
- Blockchain has been identified as a technology that could add value.
- The right supply chain parties have been identified.
- The mill has been approached and confirmed as a key partner in this venture.

Leadership activities that need attention:

- The correct human and financial capital has to be sourced and allocated.
- The skills and capabilities of each party that is require to partake in the network needs to be identified.
- The relevant technology partners and other supply chain actors have to be identified and brought on board.
- Once all the stakeholders and technology partners has been identified, collaboration needs to be facilitated between them.

Ecosystem

In this case, blockchain is intended to transform a supply chain consisting of different parties and not just one company within the network. Thus, the overall approach is more inclined to being that of an ecosystem than a silo, which is in line with blockchains, intended application.

Overall Strategy

The overall strategy of the use case is to create an information ecosystem over the supply chain to track and trace the non-GMO characteristics from farm to retailer. The learnings generated will be used to deploy future track and trace systems across more complex supply chains. The vision and strategy used in the use case is in line with the purpose and capabilities of blockchain.

5.3.3 Product architecture

Case for product and product characteristics

A case for the specific product has already been developed by the company. There is a strong need for the raw material to be tracked to in order to confirm non-GMO status. The product that was determined to best benefit from blockchain tracking and tracing is a specific non genetically modified FMCG product. This product has a specific traceable characteristic that is of importance at each step of the supply chain and has a significance to retailers and consumers. This characteristic is tested and verified throughout its journey from the farm to the retailer. The current manual/paper-based traceability system does not provide sufficient supply chain visibility. There is an interest to developed a blockchain based traceability system to track the location and nature of the non-GMO maize ingredient. This will provide end-to-end visibility in and the ability to easily verify the nature and state of the product.

The current problem is that it is often difficult to verify the origin or nature of a product as it moves through the supply chain. In this case the FMCG company has to verify that the foods are made from maize that is Non-GMO in nature. When the products arrive at the company warehouse, documentation provided with the shipment authenticate its nature and specifications. This procedure however only extends to a tier one supplier as shown in figure 5-9. The goal is to have a system where the company can view the details of the product throughout its entire supply chain journey.

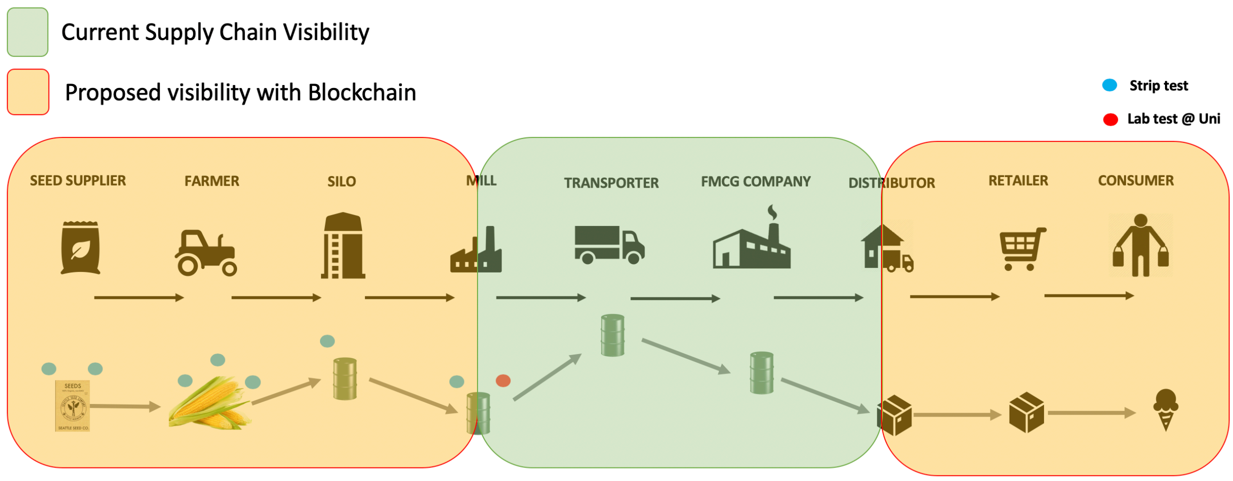


Figure 5-9 Current areas of supply chain visibility

Product characteristics and digital product identity

Leaving the Silo, the product is non-GMO raw maize. At the mill, it is transformed into non-GMO maize product and further processed at the FMCG company. Even though its form changes, the defining characteristic that is of value is its non-GMO status.

Other information used to form a product identity is reflected in the transfer document and includes information such as:

- Weight
- Date
- Batch no.
- Location
- Specification
- Production

A digital product identity is only created at the FMCG company where it is uploaded to its internal SAP system. Before this, information is handled in a paper-based manner. The non-GMO certificate and the transfer document will need to be digitized in order to create a digital product identity.

A suggested method is uploading the certificate to the blockchain and using a QR or Quick Response code to link this to its digital identity. The QR code can be generated to digitally ID a batch based on its characteristics as well as link to the blockchain showing the latest non-GMO certificate. Thus when the batch arrives at the FMCG company, all they need to do is scan the QR code to verify its origin and nature. No paperwork or manual processes are needed.

5.3.4 Supply Chain Architecture

Value chain

Table 5-2 Value analysis

Value chain	
Distinct value being achieved:	Added visibility to incoming material.
Tasks being supported:	Management of information transactions between parties.
Processes being improved:	Validation of non-GMO characteristic.
Unique characteristic being achieved:	Visibility of the non-GMO characteristic and supply chain transactions from the silo through to the inbound company warehouse. (where previously it only extended to the mill).

Transactions

Figure 5-10 on the following page shows the different information transactions that occur in the supply chain. This is representative of the transactions that need to occur on the blockchain network.

Table 5-3 Transaction considerations

Transactions	
Does the supply chain follow a transactional data model?	Yes. At each point where the raw material (non-GMO maize) is transferred from one supplier to the next, an information transaction occurs. This transaction governs the physical exchange of material and includes information.
Is identity related to the signing of transactions?	Yes. At each transaction, the identity of the supplier, its location from/to and identity of the product is recorded along with its GMO status. Information on the persons and parties involved in quality checks and validations are also recorded as part of the transaction. This information is governed by the transfer document assigned to each shipment of material.

Workflow

Would the addition of blockchain simplify workflow and supply chain processes? It would be much quicker and more efficient to check the history the non-GMO maize's transactions using blockchain than compared with current methods. The current workflow involves a paper transfer document that gets compiled and passed on with the product as it moves through the supply chain. This paper document limits visibility only to the first tier supplier (mill). The addition of blockchain would mean that all this information is uploaded online onto the blockchain as it moves between suppliers. It is updated in real time and is visible to the entire network.

Possible friction points to improve workflow, is blockchains' integration with existing IT systems. Blockchain would have to integrate with many different systems that companies have relied upon for information efficiency in order to be effective. For example, it will have to integrate with the FMCG companies internal SAP system and the other IT systems used by the transport company, mill and silo.

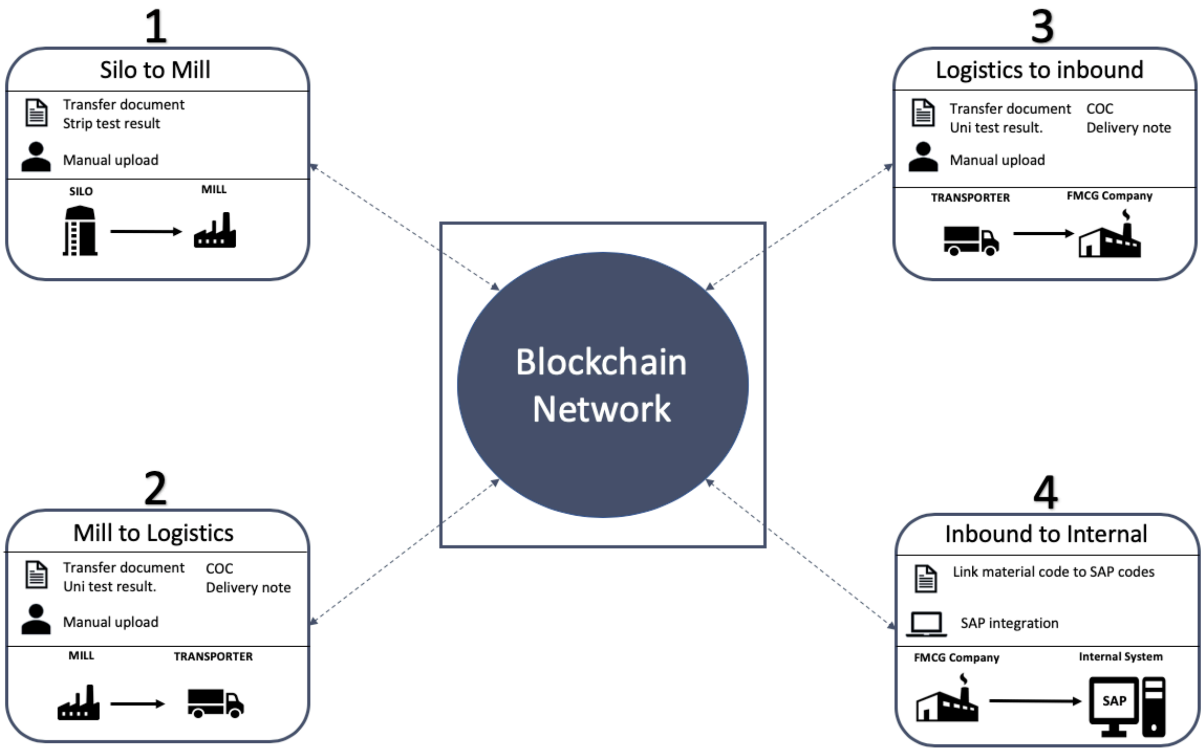


Figure 5-10 Blockchain supply chain transactions

Performance

Transaction speed is not a concern, as rapid millisecond transactions is not a requirement in this supply chain case study. That speed is more applicable to financial applications. This is because transactions involving materials do not occur on a millisecond basis. The 'minute' speed of blockchain is sufficient for this case study.

Operation

Table 5-4 Operational considerations

Operation	
Does the business deal with contractual or value exchange?	Yes. Value is the raw materials and product (maize), and the contracts are the information governing those value exchanges.
Will processes benefit from automation?	Yes. The information handling process is currently largely manual and paper-based. If the company needed to trace back the incoming raw material to a 2nd or 3rd tier supplier such as the silo, (or even farm) it would be a lengthy and very admin intensive process. Having a trusted and secure online ledger that can be accessed to find this information would greatly improve operation and automate processes.

Is there a desire to decentralize processes?	The blockchain tracking and tracing system is initiated by the FMCG company. It is important to consider that they should not have full governance over the blockchain, else, control becomes centralized and that challenges the purpose of a blockchain in the first place.

Stakeholders

The different stakeholders are the: silo, mill, university lab, logistics company and the FMCG company. These stakeholders need to be brought together to make decisions on rules and procedures that govern the blockchain network. These decisions will involve, but are not limited to:

- Deciding on what data to be stored on the blockchain?
- What data formats and standards to use?
- Who has rights and access to the data?
- How will new data be added?
- How will privacy be insured?
- How will new data be validated with a consensus mechanism?

The more nodes there are in a blockchain network, the higher the security and system integrity becomes. In the focus area of the case study, there are initially only five nodes (stakeholders). The eventual full rollout of the case study would result in more nodes and result in a higher system integrity. It is important to insure that each node has the IT infrastructure needed to be a part of the network.

Governance

An important fact to consider is that the different stakeholders involved, need to subscribe to a governance structure that drives the intended value from the blockchain system. This structure might be devoid from what these stakeholders traditionally subscribe to. It is important, because the benefits from blockchain are obtained from decentralizing trust. The FMCG is leading this initiative, thus it is easy for them to be in control or govern the other members of the network which will result in a centralization of power. Each stakeholder including the mill, silo and logistics company might need to change the way they approach ownership of data, systems and supply chain operations in order for a system as a whole to benefit.

Trust

A question that is asked by the FMCG company is, '*how can I verify that the incoming material is of a non-GMO nature*'? Usually one could verify this by looking at the certificate presented by the last transfer document, however this verification is only between the company and the last supplier, the mill. Areas of trust that need to be improved extends down from the mill to the silo. In the phase two and three deployment of the case study (figure 5-9), areas of trust are intended to be extended to the farmer and the retailer.

Incentive

There needs to be an incentive for the mill, logistics company, university lab and silo to be a part of the blockchain network. This incentive is the ability for each of them to be a part of a shared ledger system that will make information transactions, easier and more transparent. Each of the parties will have the ability to view and confirm the GM status of the maize up and down the supply chain.

3rd Parties

The university tests can be seen as a 3rd party, as they are not directly involved in the supply chain but perform an outside validation or service. The 3rd party in this case would not need to be removed or re-invented. They will essentially be unaffected. The only change would be in the method of handling information.

5.3.5 Technology Architecture

Table 5-5 Requirements and guidelines relating to the data sub-section

Data requirements	A complete immutable history of a batch of maize produces' non-GMO status is required.
Identification of SC data	An information flow study of the supply chain was done and is visible in figure 5-8. The transfer document and GMO test certificate is key to the products identity. The GMO certificate is the key piece of information that needs to be stored on the blockchain.
Privacy and Security	Personal company data such as shipment weights, dates, production info and orders might want to be kept off chain. The FMCG company and each supply chain member need to decide what data should not be shared on the blockchain.
Data capture and entry	The transfer document and non-GMO certificate can be digitized through QR codes and scanners. The non-GMO product can be also be digitized using QR codes or even by NFC or embedded RFID chips in the packaging. IOT and GPS sensors can be used by the logistics company for tracking and tracing.

IT

In the study, it has been identified that the FMCG company uses a SAP IT system. The information provided in the case study did not specifically identify the information systems used by the logistics company, mill and silo, however it is known that their systems are different to one another. In a successful deployment of blockchain, in this case study, it is critical that these systems can work together with the blockchain network. This will help streamline data management and avoid replication of data and processes at each step.

Blockchain Architecture

By evaluating the case study it is clear that there is one leading company driving the blockchain initiative and securing other independent parties in the supply chain to join. This is evident of the multiple consortium model described by O'Leary (2017) and the central hub and spoke model in Accenture (2018). These models describe a central leading entity or company which spearheads the design, implementation and operation of a blockchain network in the supply chain consisting of several other suppliers. This large market leading organization is often at the centre of the blockchain operation and wishes to gain better visibility or control over transactions in the supply chain.

This model is typical of a private blockchain, as members are pre-approved and must subscribe to the agreed upon rules or practices of the supply chain. As there are many different independent parties involved (silo, mill, logistics firm), there is a potential risk for exposing private information on such a shared network which could lead to the loss of business intelligence to competitors. A solution to this is by providing each member with a different 'view' of the blockchain network. This way, important information such as the non-GMO characteristic can be seen and validated by all yet potentially sensitive information such as orders and quantities are only visible to respective individuals involved in that transaction. Other methods would be for companies to use alternative methods of capturing and storing private information beyond the blockchain.

A concern with this architecture is that it is devoid of the original open public blockchain model that has sparked the interest in the technology. In an open network with a large number of participants who are pseudo-anonymous, the power for achieving consensus and verifying trust, lies within the crowd. In a private consortium model such as this, there will likely be power differences (due to market power/size/influence) and thus not every node will be equal. This could lead to a certain degree of centralization which contradicts the advantages of blockchain and why one would use it in the first place.

A more appropriate architecture could be to follow the consortium peers model, described in Accenture (2018), where different stakeholders (mill, FMCG company, logistics, university, silo etc.) agree to form a consortium and build a supply chain blockchain that they all use. The incentive to participate is to validate and facilitate information transparency regarding the non-GMO status of the maize product, a reason for which they all have vested interest. This model promotes all shareholders to be equal and independent in the network and will trust decentralized. However, this form of architecture is difficult to achieve and more complex than other forms of architectures.

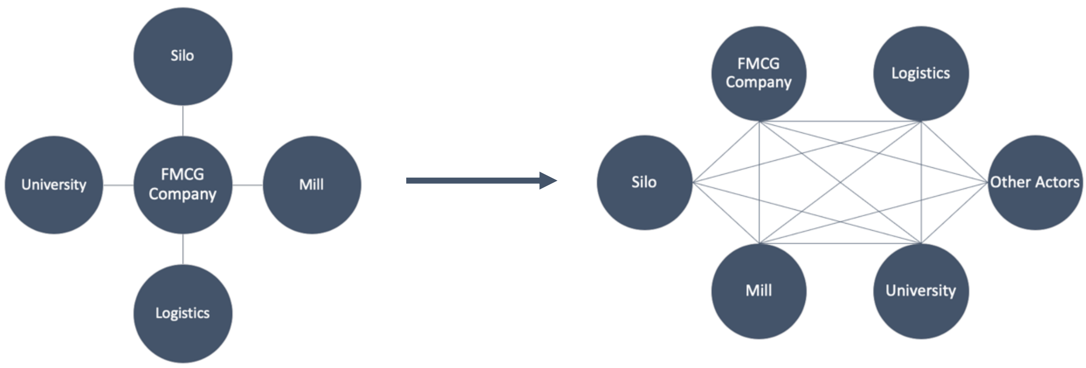


Figure 5-11 Proposed hub and spoke (left), recommended consortium architecture (right)

Mode of operation

From the case study it is evident that the blockchain should serve as a communications layer between the different supply chain parties for transparency regarding transactions of the non-GMO maize. This case is representative of a private blockchain ledger where the different participants of the supply chain (i.e. mill, silo, FMCG company, logistics company etc.) are pre-selected to join the network. The advantages of having a private network for this use case is:

- As access has to be approved, thus no unauthorized individuals can view company transactions.
- It is easier to change the functionality and governance of the network as participants are limited.

- Better controls over information privacy and governance mechanisms.

This said, a private blockchain might not be the ideal solution for this supply chain case study and neither will a public one. In a public blockchain everyone is allowed access to transactions, something supply chain companies might not want, however, there are better incentive mechanisms for trust and validation of information. In a private blockchain, there are a limited number of nodes and little incentive for validating information by means of a consensus mechanism.

A better solution for this could be in the form of a hybrid blockchain system. In this scenario, sensitive information could be stored in a private layer of the blockchain whilst important information requiring high trust can be stored in a public layer. Here, information such as orders, material volumes and suppliers can be kept private whilst the important piece of information, the non-GMO status of the produce, is stored openly in a more public ledger. Using this, it is easily possible for anyone to validate the GMO status of the material without the company risking to expose any unintended information relating to its internal operation. This is also desirable when a further extension of the blockchain occurs in phases two and three of diagram 5-7. When more parties join the network, they do so for the incentive of validating the GMO status and origin of the product. By using a hybrid blockchain, the important piece of information is more openly available and secure whilst private info is kept safe.

Blockchain Platform

Due to blockchain not being a mature technology as of yet, it is difficult to recommend a certain platform that will be 'the best to use' over others. At the same time there are many different platforms in development to suit specific needs. In the previous section, a case is made for why a hybrid/permissioned type of platform is best. Thus, a platform that allows this type of operation would be the most suitable. Due to the company using products and services from SAP, it would be reasonable to expect that they would use a Hyperledger blockchain as they have a partnership with SAP systems. However the company should evaluate its needs and choose the platform that offers the greatest blockchain advantages at the required performance characteristics.

Consensus

The consensus mechanism used would depend on the blockchain platform chosen, although in many cases such as with Hyperledger or Quorum, these platforms allow for the use of different mechanisms. At this stage in research it is not possible to recommend one consensus mechanism over another.

5.3.6 Feasibility analysis

Table 5-6 Considerations and observations of the feasibility sub-architecture

Consideration	Observation/Answer
Immutability: Does the system need a historical record of data that cannot be changed?	Yes, an immutable record of the maize's non-GMO status across the different supply chain partners is required.
Is **transparency** between actors required?	Currently, transparency is only extended to 1st tier suppliers. Transparency to 2nd and 3rd tier suppliers is required.

Does the ecosystem lack **trust**?	With regards to the previous answer, there are levels of trust between the FMCG company and the mill. Areas of trust to be improved extends down to the silo and eventually further to the farms.
Is **identity** coupled with the signing of a transaction?	Yes, in each transaction the identity of the maize product is governed by a transfer document and a non-GMO certificate.
Are there enough **stakeholders** for blockchain to be feasible (nodes security etc.)	Initially there are only four stakeholders involved, of which one is a large FMCG company. The risk is that one party can exert more control over the network and therefore defeat the benefits of decentralized trust. In future when the project is expanded there are expected to be 10 different stakeholders.
Are there information **transactions** that occur on the system?	Yes, at each stage where the maize changes hands, such as from the silo to mill or mill to logistics, there is an information transaction governing that exchange.
Are the **interests** along the SC aligned?	Yes, each supplier/party has to verify the GM status of the product either by an admin process (FMCG company) or by a physical test. Having a complete record of the products' status along the different suppliers, will greatly improve transparency and align with everyone's interests.
Is the ecosystem model supported across all stakeholders?	The ecosystem model is supported by the FMCG company however it is not known if the other parties support the same vision. Thus successful co-ordination and communication is required to achieve a full ecosystem.
Does a traditional **database** provide a better solution?	No. Thus far there is no traditional database solution. The FMCG company have their internal tracking and tracing system (SAP) and each other company have their methods of doing so. There is no end-to-end tracking solution. Blockchain could be a system that facilitates communication between all the different companies and their systems.
Is there a likelihood of **data** being falsified?	In this case there is no evidence that suggests that one entity might want to sabotage operations by falsifying data. This does not exclude the likelihood of it occurring in more complex supply chains.
Can assets be **digitalized**?	Yes, by digitizing the transfer document and GMO test certificate, an asset can be identified and its nature determined.
Can a **permanent** record be created/would it be advantageous?	Yes. Having a permanent record would be advantageous. If there are any quality or health issues with the final product, its history can be traced back. It also provides assurance.
Is there an exchange of **contracts** or **value**?	Yes, the physical product represents value, whilst the information identifying them serves as contracts between suppliers.
Do you intend to store large amounts of **data** on the blockchain?	The key piece of data is the non-GMO test certificate proving the products' identity. This is not expected generate large amounts of data.

Is **centralization** of system operation desired?	It is not possible to answer this question without knowing the true intent of the company's strategy. It would be in every party's best interest to support decentralized control.

5.4 Blockchain Design Recommendations

After evaluating the case study with the reference architecture, a summary of the main findings and recommendations is presented in the following subchapters. In 5.4.1, the main design guidelines and recommendations will be stated followed by a concept design based on these guidelines in 5.4.2.

5.4.1 Design guidelines and recommendations

After consulting the design reference architecture developed and applying it to the non-GMO maize supply chain case study, there are a number of recommendations and guidelines that the FMCG company should focus on:

Digitalization strategy should focus on creating a supply chain ecosystem

- Apply correct methods to record, digitize and upload data.
- They should focus on ensuring the correct enabling technologies and capabilities are in place at the mill, logistics provider and the silo. Methods to record, digitize and upload data need to be universally in deployed to ensure that assets can be digitized.
- The plan should involve the interaction of existing business processes and information systems such as SAP with blockchain.

The FMCG company should spearhead the leadership and adoption of blockchain in the supply chain

- The advantages of blockchain technology in track and trace should be communicated to the mill, silo, logistics company and others involved.
- The correct human and financial capital should be aligned to implement the project.
- The right technology partners need to be identified.
- Collaboration between all the stakeholders need to be facilitated and focus should be placed on the importance of decentralized governance for system integrity.

In terms of the product:

- Correct product digitization is very important. The physical identity covered in the transfer document and non-GMO certificates need to be digitized. Suggested methods are the use of QR codes that can be easily designed to display the details when scanned and provide a link to the blockchain. It's important that these processes are automated to minimize risk of incorrect data entry.

In the initial scope of the implementation, there are four different blockchain transactions that occur.

- Silo to Mill, Mill to Logistics, Logistics to FMCG company, and FMCG company to Internal. Additional 3rd party transactions involves the test result from the university.

The different supply chain stakeholders (mill, silo, logistics etc.) need to be brought together to make decisions on:

- Governance structure.
- What exact data needs to be uploaded onto the blockchain.
- Which data formats to use.
- Privacy rights, what data must be published to the blockchain and what must be kept private.
- What methods will be used to add new data.

Identification of supply chain data

- The transfer document containing the product information needs to be digitized along with the non-GMO certificate.
- The non-GMO certificate is the key data element that needs blockchain validation. This element is of interest to each stakeholder, thus it will be advantageous for them to share it openly.

Blockchain architecture recommendations

- The hub and spoke architecture formation would develop naturally in this smaller supply chain example. A consortium architecture however, is more true to the nature of blockchain and would be preferred for future implementations albeit harder to achieve.
- A hybrid/permissioned type of blockchain should be the preferred type of blockchain used. It will allow privacy controls over who can read/write private data (such as the transfer document) but allows open transparency for the one important element needed for visibility, i.e. the non-GMO characteristic.
- An important observation that was made: For these types of cases, private blockchains seems to be the most desired for companies due to privacy concerns. However, the true benefit of blockchain is obtained by using a public ledger to introduce immutability. New advances are making it possible to incorporate public ledgers with private ledgers to suite a company's needs. Thus, companies should not ignore the benefits of public or hybrid blockchains in favour of private blockchains.
- It is difficult to advocate which exact platform and consensus mechanism to use. There is no clear conclusion as to which is best. Most supply chain case studies either use Ethereum or Hyperledger, however there are many new improvements on Ethereum with improved scalability. Platforms are still rapidly developing and evolving at a high pace to address issues such as privacy whilst still retaining immutability and efficiency.

Other applicable guidelines:

- Stakeholders need to collectively agree on governance, data standards, data upload methods, privacy and restriction of sensitive data.

- FMCG company should focus on and promote a decentralized control ecosystem.
- For improved supply chain workflow, the solution needs not to replace existing IT systems but integrate with it. Such as the SAP system used by the FMCG company.
- There needs to be a direct incentive for each stakeholder to be involved in the blockchain track and trace system. In this case the incentive is the ability to have supply chain visibility over the non-GMO characteristic of the product.

5.4.2 Blockchain IT system design: high level overview

A blockchain concept design and overall IT system overview is out of the scope of the design reference architecture, however, it was decided to include it in this study. The reason for this is to enhance understanding of how the guidelines will influence real life system design decision making. The goal was thus to use the recommendations from the architecture, along with research on blockchain tracking and tracing systems to produce a high level overview of a concept system design.

The IT system design layout was based on research presented at the blockchain supply chain innovation conference in Frankfurt 2019 which the author attended. Research presented there detailed the where blockchain exists in the overall enterprise architecture and how it interacts with other processes (von Perfall, 2019).

High level overview

Figure 5-12 illustrates the placement of the blockchain component in the supply chain track and trace use case. The physical layer is the supply chain processes that occur in real life. In the case study this is where the maize is transported to the mill, refined, tested and shipped to the next location for example. The digital layer is where information from the real world processes are collected and digitized. This is where process information is recorded, digitized and uploaded to ERP systems, management software and other systems that each stakeholder uses. The application layer is the traditional digital components that make up the supply chain. Apps, web services, business processes, management software and IT systems that is used and managed by the supply chain.

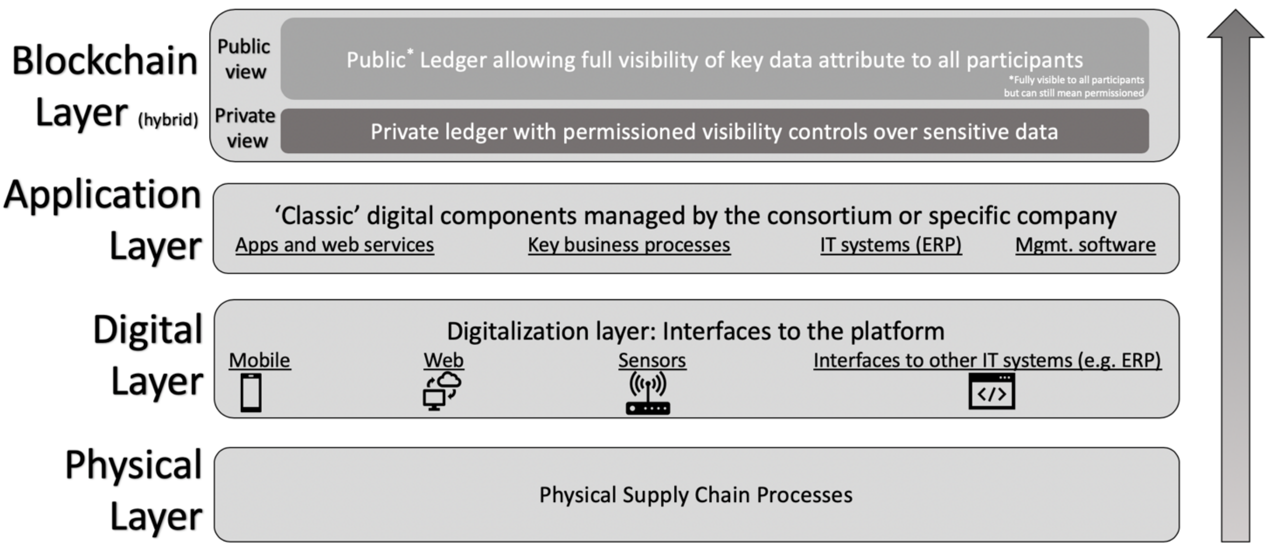


Figure 5-12 High level conceptual design of the blockchain system components

The last layer is the blockchain layer which spans across the entire supply chain. In the architecture, it was motivated that this case study makes use of a hybrid blockchain platform as pictured in the figure. This means that the blockchain has two different sections. Data in the public ledger is visible to everyone that is a part of the network and forms an immutable record of the products non-GMO test results throughout the supply chain. This can be used to verify its nature at any point. The private layer has certain restricted views, meaning it is not open for all members of the supply chain to see. This houses data that two suppliers might share with one another but not necessarily with others further down the supply chain. This could include some details in the transfer document in this case.

High level track and trace design

Figure 5-13 below shows an example of a possible blockchain track and trace solution for the non-GMO maize supply chain. It offers greater detail of the figure shown previously, but keeps to the same design layout. QR codes are used to digitize the products identity and link it to the blockchain. When scanned, it can showcase the blockchain ledger containing the non-GMO certificates for that specific batch or item. In this way, any stakeholder along the supply chain can verify its non-GMO characteristic. The certificates are stored in the public ledger where everyone can verify its nature. More sensitive data such as agreements and terms found in the transfer document can be stored in the permissioned private ledger.

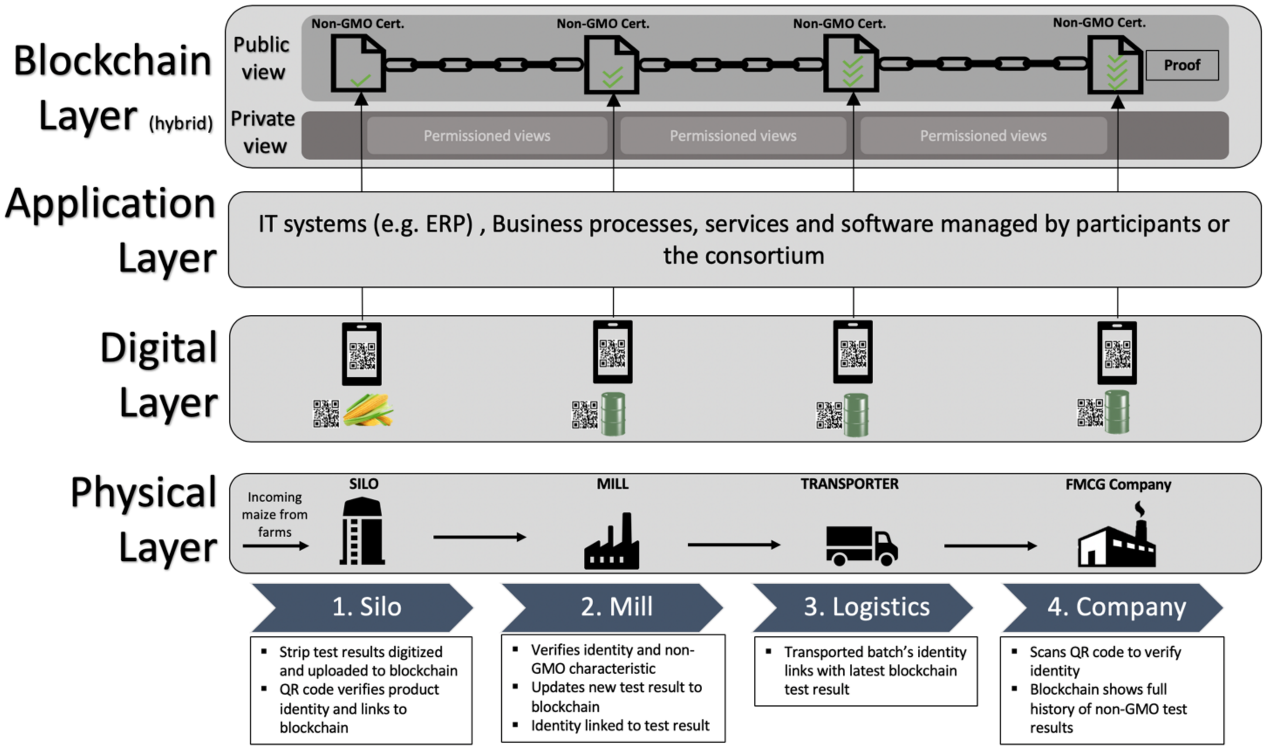


Figure 5-13 Conceptual design of blockchain track and trace system

5.5 Comments on case study application

After evaluating the case study using the design reference architecture, some comments can be made:

- After blockchain has been deemed feasible and strategically advantageous to use in the use case, it is important to first conduct a full information flow study of the supply chain before commencing with the other sections of the architecture. The information gathered in the information flow study, figure 5-8, was key to the evaluation of the case study. This guideline *'Identification of SC data'*, is under the Data section in the Technology architecture

- In this case, the case study was already determined as feasible by the supply chain company. In theory one would first consult the architecture before determining the case study feasibility. Nevertheless, evaluating the case study was still a good demonstration of showcasing the practicality of the architecture in industry.

5.6 Case study Validation

5.6.1 Validation Procedure

In this subchapter, the case study validation at the FMCG company will be presented. The results and recommendations generated in section 5.4 along with the case study evaluation was sent to a corresponding expert at the company. The blockchain/supply chain expert in charge of the blockchain case study application at the company had time to evaluate the reference architecture recommendations. The expert then provided feedback based on the following key points:

- Are the guidelines valid and helpful?
- Are the guidelines relevant to the case study?
- Would this aid in decision making surrounding the design of blockchain systems for the supply chain?
- What general recommendations or improvements can be made?
- Does the conceptual design aid in illustrating the architecture of a track and trace solution based on the recommendations generated?

In addition to this, the expert will also to provide specific feedback and comments on the guidelines presented as well as specific feedback on the conceptual system design.

5.6.2 Validation results

Table 5-7 General feedback based on the generated recommendations

	Overall feedback on DRA guidelines
Question	**Feedback Received**
Are the guidelines valid and helpful?	Yes. It does 3 things really well. First it formalizes a collection of information and knowledge on blockchain in a variety of different aspects into one document – this is extremely valuable to the industry. Second, it provides a framework of thinking to ensure that you have not missed anything and that all relevant decisions are made with the correct birds-eye view. This is again important especially as there are limited companies and therefore limited resources that have successfully implemented a running solution (of those resources, almost nobody would be internal to FMCG companies). Thirdly, it provides a very clear way of deciding which product this technology can add value to – something I don't think anyone has cracked yet (which results in a whole lot of wasted time and effort in the exploratory phase of this technology).

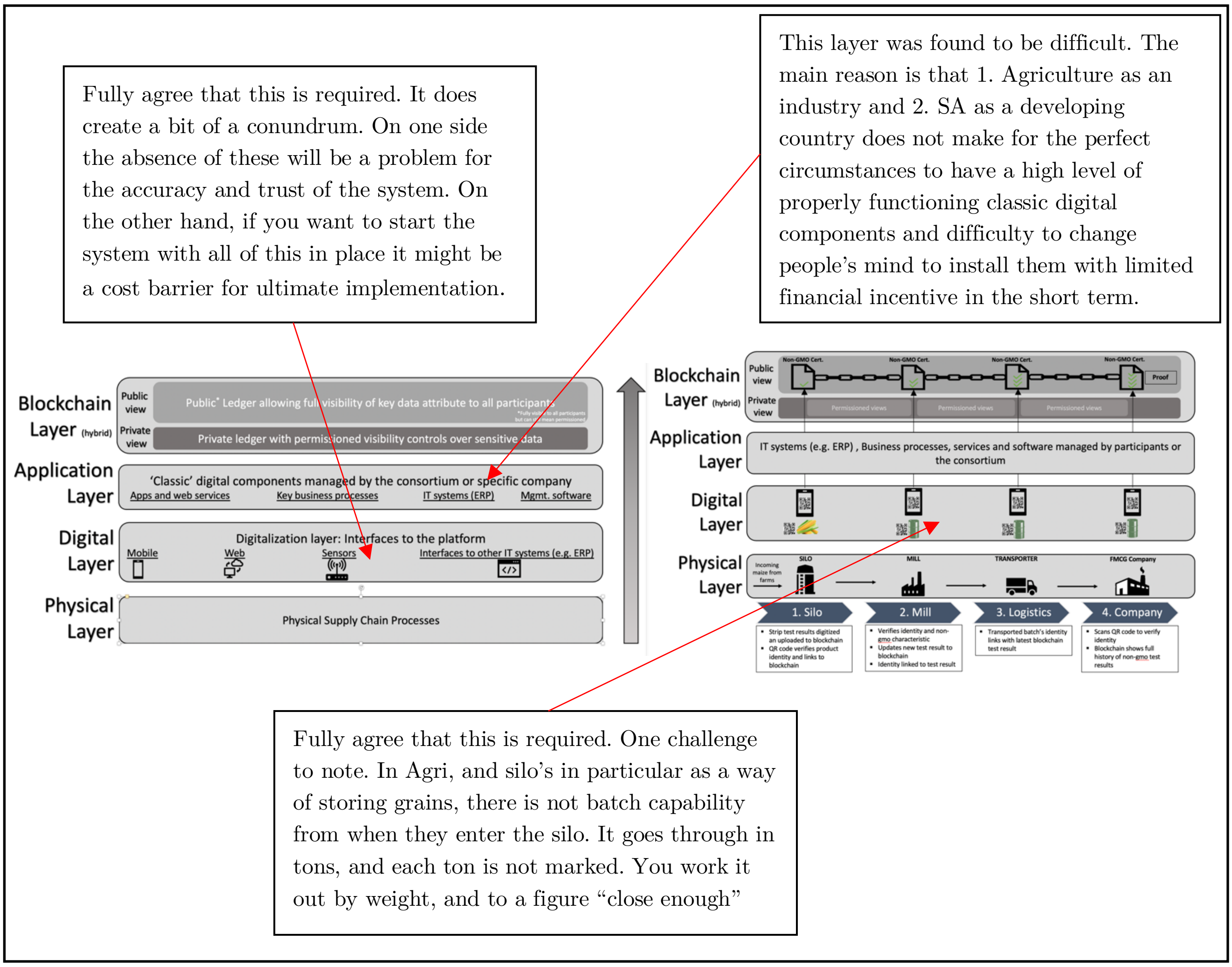
Are the guidelines relevant?	Yes, they are. Applied well by the author. The case study had a couple of key weak points which the author addresses successfully.
Would it aid in decision making?	Yes, it would. Using the whole framework from the first day of the blockchain project would have saved a lot of time, effort and costs. It would also provide the opportunity (when implemented effectively) to ensure well aligned stakeholders on the positives and negatives of the technology.
General recommendations and improvements	The research should note the context (country, economy, industry) in which it takes place, which can differ dramatically from others. Note that any blockchain study should start with a feasibility study and a why, after which data validation (and in this case digitization) becomes key first steps. Clear difference between provenance and traceability. Business cases should include a quantitative benefit of doing it (vs costs), as well as a quantified cost of not doing it. Change management to be a key unlock.

Table 5-8 Feedback and authors response on specific guidelines

Specific Guideline Related Feedback		
Guideline in 5.4	Feedback	Authors response
They should focus on ensuring the correct enabling technologies and capabilities are in place at the mill, logistics provider and the silo. Methods to record, digitize and upload data need to be universally deployed to ensure that assets can be digitized.	This is a key characteristic that serves as a basis for the implementation of any tech. The only problem was that it would 1. Increase cost, 2. Increase buy-in needed from upstream supply chain partners to change their business with limited financial benefit to them, and 3. Can be a time consuming task on its own, which is difficult to align with your leadership teams and stakeholders.	The author acknowledges that enabling tech can be costly at first. However, as blockchain improves, improvements and innovations in enabling technologies would reduce costs and time. For example, the use of mobile phones and QR codes. As this is not a business plan, a cost study is outside of the project scope.
The right technology partners need to be identified.	Absolutely agree. One note, always a balance of time, cost and quality. We found that in blockchain, less time and less costs work better in the pilot phases.	
The different supply chain stakeholders (mill, silo, logistics etc.) need to be brought together to make decisions	There is a delicate balance between the organisation leading the implementation (and probably paying for the system) dictating this, and collectively making the decision. Furthermore, I agree with a hybrid as mentioned later, and should be aligned here as well.	

FMCG company should focus on and promote a decentralized control ecosystem.	There is a definite barrier in terms of 1.Internal controls (not giving away sensitive data, with total volumes of a product sometimes being sensitive) and 2. Internal stakeholders in a large FMCG company doesn't like the idea of decentralized control, a direct paradox to the use of blockchain.	Decentralizing trust is the key ability providing its advantages. Companies need to understand that there is more to gain through decentralization. Better education and knowledge will further this understanding.

Feedback on conceptual system design



5.6.3 Validation conclusion and response

Overall the case study evaluation was positive. The feedback indicated that the guidelines derived from the reference architecture enhance decision making and formalized a collection of knowledge that will guide teams and help save time/money. This is precisely the intended purpose of the reference architecture as well as the overall aim of the thesis. Important factors that that were highlighted was the need to first consider the feasibility aspect of the architecture. The expert stated that cost factors and economic conditions of individual cases can have an impact on decisions. The author agrees on this fact, however the inclusion of those factors are more suited to business plans and is outside the scope of this thesis.

5.7 DRA Feedback and Validation

The following subchapter will comprise of feedback received from external industry experts regarding the design reference architecture. The experts will analyse and evaluate the architecture after which validation feedback will be gathered by means of an interview. The feedback gathered from the experts will be used to help validate the quality and applicability of the architecture.

In terms of identifying the experts, blockchain is a very new technology and its application in supply chain less than five years old. It was initially very difficult to identify experts in both blockchain and supply chain. In order to qualify as an expert, the person has to be professionally involved in blockchain and/or supply chain development/engineering as a career and have had formal qualifications and demonstrated industry expertise. Experts were identified through online research, networking at blockchain conferences, recommendations and at the partner company.

After they were identified they were contacted via email and informed of the masters project whether they would be willing to act as independent experts in the validation of the architecture developed. They were informed of the ethical considerations and that their personal information would not be published and kept private.

The structure of the feedback interview was as follows: The expert would have had time to study the architecture and its details in advance. In the interview, the author would do a presentation of the design reference architecture, explaining its detail. After that, the expert gives specific feedback, evaluation and recommendations on each of the different sub-architectures. After this, the overall validity of the architecture is discussed based on 3 factors:

- Content validity: are the important elements included in the architecture?
- Application and use: is the architecture easy to use and suited to the intended application?
- Practicality: will it be useful in practise?

After this has been done, the author will also ask the general opinion of the expert on the validity of the project and how it relates to their experiences in working with blockchain in practise. This will aid in obtaining an external perspective on the current climate of blockchain technology in the supply chain, what the current challenges are and how this architecture can play a role the furthering of knowledge in the field. Notes will be taken throughout the interview process which will be typed out and used in the validation after the interview.

5.7.1 Validation at multinational FMCG company

Overview

This validation procedure involved experts in blockchain and supply chain at a large multinational FMCG company. The company is currently in the process of testing blockchain technology in their supply chains to aid increased visibility. Two experts were identified at the company, both of whom are supply chain professionals with further specializations in blockchain. The one expert is directing the development of a blockchain supply chain pilot project and has a further education in blockchain technology. The other expert is the director of digital transformation at the company and specializes in supply chain digitalization. He has further specialized in blockchain at the University of Oxford (UK) and is leading the adoption of blockchain in the company. Names and other personal details including the name of the company was held private as per the ethical agreement.

The process focused on the validity and applicableness of the Design Reference Architecture in supply chain track and trace. A summary of the reference architecture along with a full detailed writeup was sent to the two experts about two weeks ahead of time in order for them to familiarize themselves with the work. An hour long skype interview was then set up, where they could give their feedback regarding the architecture. The feedback involved a detailed discussion of each section of the architecture, followed by an overall evaluation based on three criteria:

- Content validity: are enough of the important elements included in the architecture?
- Application and use: - is the architecture easy to use and suited to the intended application?
- Practicality - will it be use-full in practice?

First and foremost, the experts clarified that there is currently low adoption rates in industry due to a lack of understanding around the technology. Even for experienced blockchain professionals, there are still many aspects that are not clear. The difficulty is often to explain blockchain to senior executives in order to get the green light on supply chain projects. They believe that there is a need for a tool that can help them better understand the various aspects of the technology in a supply chain environment. Once the first successful blockchain project is launched they believe that adoption will be rapid across the industry. They also stated that there are currently low levels of trust across the supply chain which results in many different problems, and that blockchain is a possible solution to these challenges.

Results

The following table details the feedback made by the experts.

Table 5-9 Interview feedback - FMCG company

Overall remarks	In terms of the evaluation of the overall design reference architecture, they were pleased with the work done and stated that it is a very good summary of all the different guidelines and aspects involved in the design of blockchain tracking and tracing in the supply chain. They felt that it covered enough content and included most of the important elements needed. It was stated that the architecture can help advance understanding of the technology in the supply chain.

Strategy and overall Structure	In terms of the structure, they agreed on the different sub sections presented. It was clarified that they felt that the feasibility section was perhaps the most important section and needed to be considered before some of the other sections. It is important to first consider the reason and value for having blockchain before commencing with it.
Product architecture	In terms of the product architecture section, they agreed with the fact that whenever there is a product claim such as a specific origin or characteristic that the product viable for a blockchain use case. Overall its structure and elements were sound.
Supply Chain architecture	They felt that the supply chain architecture section was well done and very comprehensive/thorough. The human factors mentioned in the stakeholder section are often the most important, yet the most difficult to address. In real life, power balances between stakeholders could make it difficult to obtain decentralized end to end collaboration.
Technology architecture	The technology architecture section was found to be helpful because it identifies and groups all the different design elements together in one place, something that has not been seen before. They understand that at this stage, it is difficult to recommend a specific platform or structure over another. However, having them together enhances decision making. Within the case study they agreed on the recommendation of a hybrid consortium structure for blockchain in the supply chain as opposed to an openly public or strictly private ledger.
Feasibility	The feasibility section was described by them as one of the most helpful and important parts. It contains a good set of questions to help screen the feasibility of the project. One point that is perhaps worth adding is: what is the cost of not doing blockchain as opposed to using blockchain? Overall this section included some good questions and considerations

Summary and Recommendations

The experts felt that this was a good architecture to help guide the design and development of blockchain tracking and tracing in the supply chain. It addressed the main, problem which is that there was no central source of knowledge, tool or framework in this area.

- A good point that made was that this architecture could be used as a basis for designing a basic blockchain summary for supply chain professionals. A 1 – 2 page summary with expansions that summarize the findings of the different sections i.e. feasibility, strategy, technology etc.
- Another point made in terms of structure is that it is important to start with the feasibility and strategy sections first. Currently blockchain is being used in many use cases for which it is not suited and eliminating those will save time and money. By starting out with the overall strategy and feasibility one could answer the question, 'what is the reason for having blockchain in the first place?'. After this a full dataflow analysis should take place to gather all the necessary information needed for the other sections.

Response to validation

The author agrees with the expert's overall evaluation of the architecture. The purpose of the study was to design an architecture that can form a basis for enhancing knowledge and assisting with the design of blockchain track and trace systems in the supply chain.

In response to the recommendation they added that the feasibility and strategy sections should first be consulted before the rest of the architecture. This is the intended approach of the architecture. The feasibility section and strategic intent sit outside of the core architecture section. That is by design to show that these activities should first be done before going into the inner architecture sections.

In response to the comment that this architecture can be used to formulate a further summation or business model: The author agrees that this would be beneficial but something that can be done at a further stage. Blockchain is very new and the main focus was first to identify and group the requirements. The architecture already provides a summary of all the different guidelines and requirements from a large number of sources and case studies. Further studies can focus on the design of a business model.

5.7.2 DRA validation at Blockchain Technology Consultancy

This validation took place at a blockchain technology consultancy. The company offers blockchain training, consulting and development services to clients across multiple countries. Clients usually involve banks (such as ABSA & Standard Bank), large corporates, insurance companies, government divisions and other entities. They offer training and development on platforms such as Hyperledger and Ethereum which are key platforms in supply chain use cases. A semi structured interview was done with one of the consultants at the company. The consultant is an engineer and has been working on blockchain technology since its inception. He is also an expert on the technical and mathematical side of the technology. The process followed a similar format as the previous evaluation and a skype interview was done where the design reference architecture was evaluated.

Results

Table 5-10 Expert feedback from blockchain consultant

Section	Expert Feedback
Overall Structure	Easy to understand and a good summary of blockchain knowledge for the supply chain. Can be very useful in industry.
Strategy	The 3 factors listed under the strategic section key to the application. Leadership is probably the most important. One of the main reasons it does not work in practise is because people don't understand blockchain. Companies are not yet sold on the idea of transparency as they don't want to show their books to others. The human side is key. Something that has to be clarified is blockchain is a win-win situation for all companies involved. One has to identify where the shared ledger interest is and that's what will be on the blockchain. Overall the factors listed here are important and key to the application. The biggest strategic challenges is the human element and the mindset change of companies. It is difficult to get everyone together on a blockchain. In theory it sounds great but in real life it is difficult.

Product architecture	Agree with the product architecture section, it includes all the important points. Digitalization of the product is again one of the most important aspects. IoT will play a big role in this. Digital capabilities across the supply chain needs to be in place first before a blockchain is considered (something that was mentioned in the strategic section). Overall this section is very applicable. The case for the product is also very important. There has to be a value in the use of that specific product in the blockchain.
Supply Chain architecture	Very good comprehensive summary. The aspect of stakeholder incentives are especially important across the supply chain. Overall the elements covered in this section are comprehensive and present a good summary.
Technology architecture	This section includes most of the important technical elements and considerations needed for blockchains application. These are the main decisions that need to be looked at. In terms of the public vs private debate. Many of the benefits of a blockchain are lost if its private. However, many of the benefits can be re-introduced when you timestamp a private blockchain on a public blockchain. Thus, every hour you timestamp the hash of a private blockchain on a public blockchain. In this way you re-introduce immutability. With the hash you cannot go back and change data. Bootstrap the abilities of a public blockchain on a private blockchain giving a lot of trust. Although this method has not appeared in any implementations as of yet apart from a few cryptocurrencies. The main considerations are covered here. Read and write access and who runs nodes etc. are important. It is precisely the important aspects that are mentioned here. In terms of consensus mechanism evaluation, you can evaluate them all on a scale of trust. Consensus mechanisms that are robust and trustworthy are normally slow and inefficient but that's the price of their resilience. The faster and more efficient they are the less secure normally.
Feasibility	The trust aspect here is the most important. If there is no need for trust there is no need for blockchain. Blockchain makes trust free and if trust is already free then blockchain is not needed. Other important factors covered listed is the digitalization aspect of assets. If assets can't be digitized and the system has to allow on manual input then blockchain will be obsolete. Data on the blockchain is only as good as the data entered. If bad data gets in then that bad data will be immutable. Thus digitalization of assets aspect is important.

Further comments by the expert

Currently, big companies are focused on private blockchains and are not in favour of public blockchains. Most of the benefits disappear when a private blockchain is used. There is no incentive or immutability. There are methods to incorporate immutability into private blockchains with the use of timestamps. You can timestamp a digital asset on a public blockchain which will make its identify undisputed.

In terms of blockchain overall, there is no formal definition of blockchain. This is due to a lack of academic research. Most research and developments are informal and done outside of academia. The last 10 years has seen major advances in cryptography allowing for major improvements and new type of implementations such as distributed ledgers. Although they are often described as blockchain, they aren't always true blockchain, and many of them are cryptographically improved databases.

There are many cryptographic and technical aspects that allow for the blockchains to be configurable to suite needs. Blockchains will be able to cater to the privacy needs of companies whilst still retaining an immutable ledger. These aspects, however, are more 'in depth' and specific, thus are not needed to be covered in this study. They are more suited to the study of the in depth technical aspects revolving around the mathematics and cryptography of blockchain. It would also be difficult to sell or explain to companies or non-experts at this stage.

Overall remarks on the architecture and study

Blockchain is still very early in its development. Things are changing fast, thus it is difficult to undertake it as an academic study. The reference architecture is easy to understand and is a good summary of blockchain knowledge needed in the supply chain. It contains the important aspects and considerations needed. It will be very useful in industry.

Response to validation

The author agrees with the overall comments and recommendations of the validation. The expert pointed out some considerations, which according to him are quite important in the application of blockchain technology. These considerations were:

- The people side of a blockchain implementation represented in the strategy section. How to get the right people onboard and change their mindsets. How to convince companies that opening up some information is beneficial. Destroying the notion that blockchain means competitors will be able to view all your data.
- Having the right digital capabilities across the supply chain such as IoT in order to digitize data. Data entry needs to be accurate and robust otherwise blockchain will not make sense. The asset digitalization capabilities are extremely important in a blockchain implementation and should be looked at first.
- The facilitation of trust. If there is already high levels of trust in the supply chain then there is no need for blockchain. Blockchain is only useful if trust needs to be created.

It was positive to see that the architecture designed strongly reflected these important considerations. This means that it is largely relevant, useful and in line with its purpose. The expert also included a list of technical architectural requirements that he himself has collected through working with blockchain use cases. This list was added to the appendix and was compared to the guidelines listed in this reference architecture.

5.7.3 DRA Validation at a leading blockchain focused software development company

This validation took place at a software development company specializing in blockchain development and high end, high quality custom software. They build blockchain based applications using both public and private blockchains for clients across the world and are at the forefront of blockchain development. They have a team of blockchain engineers that are working on plans to change the nature of how certain industries operate through their contributions to blockchain application development. The company also acts as a digital and technical consultancy. An interview was set up with the companies Chief Technology Officer, an experienced developer with expertise in complex systems, intelligent logistics, blockchain development & its applications in industry. The interview and validation process followed a similar procedure to the previous ones conducted.

Results

Table 5-11 Expert feedback from blockchain developer

Section	Expert Feedback
Overall Structure & Content	This is definitely applicable. In terms of overall applicableness and content relevance it is good. It has combined all the main aspects about blockchain without any of the confusing technicalities. There is a big need for a unified framework such as this, it is not something that has existed before (in their knowledge).
Strategy	Relevant and important.
Product architecture	This section is good. Applicable to tracing in the supply chain.
Supply Chain architecture	Really good section. The trust aspect is important and covered well here. One of the important considerations is what is the trust gap or who are the trusted parties. Also the fact of stakeholders and 'are there enough stakeholders and are they willing to provide the correct technical resources' is included. Security surrounding achieving identity is an important aspect that can be looked into. Requirements around transaction speeds are also listed and of importance.
Technology architecture	All very thorough, looks good. Common misconception is that in a blockchain network facilitates trust so they don't need trust anymore. The problem is that trust is now place in the IT system thus the IT and digital component is important. All the main points listed here.
Feasibility	All very important points. This section is key as many cases on the consulting side found that companies in fact do not need a blockchain.

Further comments by the expert

The problem is that many companies do not understand what a blockchain is and confuse it with cryptocurrencies. Its fundamentally about sharing information. There is a lot of press and hype about blockchain. Many are talking about proof of concept tests that have been done and presenting them as real life successes. In terms of actual real world implementations, they are quite rare. What is important to understand is how will blockchain connect to actual translated value in the real world. An important consideration that was not seen in the reference architecture but what might be important, is the aspect of security. A blockchain is only as good as the security model surrounding the achievement of digital identify.

The framework (Reference Architecture) presented here pretty much covers all the aspects that the company deals with in its applications. There is to not anything like it that have been found and we (the expert) would like to obtain a copy of it, if possible. There is a big need for a unified framework like this and it could be very useful in practise.

Response by the author

The author is pleased with the responses given by the expert. His opinion on the current state of blockchain in industry and the problems it is facing is similar to the accounts given by the other experts. In response to the comment on the security aspect of achieving digital identity. This is important in the blockchain supply chain network because if the identity of a product can be digitally falsified, then there is no point in having an immutable ledger (as data on it will be corrupted). The aspect itself, security of digital identity, is a more advance technical consideration that is considered at a further stage of blockchain implementation. The main aspect that covers this is however addressed in this architecture in the 'accuracy and robustness of data entry' requirement under the technology sub-architecture. This consideration involves aspects such as securing digital identity in order to ensure that data entered onto the blockchain is accurate.

5.8 Conclusion and discussion of validation results

This chapter presented a two-part validation of the design reference architecture discussed in chapter four. The first part involved a blockchain tracking and tracing case study in the FMCG supply chain. The second, semi structured interviews with industry experts on blockchain/supply chain. The case study tested the practicality of the design reference architecture and provided a base from which expert feedback could be generated by the experts involved in developing a blockchain track and trace case study. The feedback from experts in the industry tested the content validity, need and usefulness of the design reference architecture. A summary discussion on the validation feedback will be presented below.

5.8.1 Summary and discussion

Summary of results

The results from the expert validation showed that there was a consensus between the different experts in terms of the DRA's content validity, application and practicality. The following points were made clear by the experts regarding the DRA:

- It formalizes a collection of knowledge to advance understanding and application of blockchain in the supply chain.
- It covers all the main aspects involved in the design of blockchain track and trace, providing an excellent summary of the different components and important guidelines
- It aides in efficient decision making, saving time and costs.
- The feasibility aspect is very useful in identifying the right use cases. The guidelines on trust, strategy and stakeholders incentives are especially important in industry.

Further, the experts motivated that, in industry, there is a big need for a unified framework or architecture, such as the DRA presented, that combines all the main aspects surrounding blockchain without the confusing technicalities of the technology. There was agreement that the reference architecture is useful and will be helpful to address the current problems experienced in industry.

Differences and recommendations

The differences noted were in terms of the recommendations or improvements that can be made. The experts are from different backgrounds in blockchain (supply chain, consulting, development) thus had different viewpoints.

The following was recommended to be considered:

- Including an economic component, such as a cost/benefit analysis or context of application.
- It's important to start with the feasibility component first (along with strategy).
- The aspect of securing digital product identity is also worth noting.

These are important considerations and are applicable to the case of blockchain in the supply chain. Concerning the economic and costs component, this consideration, although noteworthy, relates more to a business plan and is outside the scope of this study. This study focuses on the important blockchain related supply chain guidelines. The costs aspect is a topic for a further study.

The feasibility and strategy sub-architectures are positioned on the outside of the reference architecture thus, are designed to be considered first. It is important to first ask the question 'why blockchain' before commencing. In future, an implementation architecture or framework can be designed showcasing a more detailed inter-relation between the components in terms of implementation steps. Due to the current lack of successful implementations, there is not enough information to make this possible.

Concerning the recommendation on securing digital product identity, this relates to the 'data capture and entry' section of the technology sub-architecture. This section refers to the robustness, accuracy and methods off data entry which is used to secure the products digital identity. The experts recommendation is a more in depth component of that specific guideline.

Reflection on the current state of blockchain in industry

The current challenges experienced with blockchain in industry reflected the findings made in this thesis. Blockchain has experienced high levels of hype with no successful real world use cases. The companies that the experts have consulted do not understand blockchain and the various aspects/decisions involved. Current explanations involve too many of the technologies complexities, making them hard for those new to the technology to understand. Companies are still hesitant on decentralization and the open sharing of information, key elements of blockchain tracking and tracing. They thus consider private ledgers which are devoid of blockchains true advantages. The costly investment required to set up a blockchain network including convincing partners of its use and advantages, is a barrier to implementation. There is not much research or guides that address these issues.

Conclusion

In conclusion, the expert feedback motivated the applicableness and validity of this reference architecture. It supported the fact that such a tool is needed and it provided the right content in order to address current challenges. This concludes the DRA validation chapter, in the following chapter the conclusion of this thesis will be presented along with recommendations on further research.

Chapter 6
Summary, Conclusions and Recommendations

In this chapter, the following will be discussed:

- A research summary will present a brief overview of the work done in this masters thesis.
- The main research findings and conclusions will be presented.
- The research contribution will be highlighted.
- Finally, limitations will be discussed and recommendations for further research will be made.

6.1 Research summary

In this masters project, a Design Reference Architecture for the use of blockchain technology in the supply chain was constructed. The aim of the architecture is to provide design guidelines, requirements and considerations that would help guide supply chain companies and professionals in the design of track and trace solutions using blockchain technology.

A literature review was first done to obtain a comprehensive background on the topic. It defined the role of blockchain tracking and tracing in addressing current supply chain digitalization challenges. Blockchain technology was examined, and its latest technological architectures analysed. An overview of existing supply chain case studies was also provided, along with their characteristics.

Following this, a methodology was formulated for the design of the reference architecture. The relevant blockchain frameworks from academia and track and trace case studies were identified and the key requirements in each were extracted. These different requirements were characterized, grouped and used as the basis for building the architecture. Existing reference architectures in supply chain and information systems were used to help guide the design.

The overall Design Reference Architecture was constructed featuring Strategic Intent, Feasibility, Product, Supply Chain and Technology sub-architectures. Each of the sub architectures contains important guidelines that need to be considered for blockchain track and trace systems in the supply chain. Teams and companies can use the architecture as a body of knowledge for the design of blockchain supply chain systems.

The architecture was then validated with the help of a case study and semi structured expert interviews. A blockchain track and trace case study was set up with a large multinational FMCG company to demonstrate the practicality and applicability of the architecture. Recommendations, along with a concept design, was generated by the reference architecture which was evaluated by the company. The architecture was also evaluated by industry experts. Semi-structured interviews were done with blockchain/supply chain experts. The feedback, along with the case study validation, was then used to form a conclusion on the validity and applicableness of the design reference architecture.

6.2 Research findings and conclusions

In this section, the key results and findings will be highlighted. An overview of the main purpose will be given followed by a demonstration of how each individual research question (RQ) was answered. In addition to the research findings, a conclusion will be made.

The aim of this thesis was to construct a design reference architecture for the use of blockchain technology in the supply chain. This was done to address a specific problem based on the following research findings:

- Blockchain is a revolutionary new technology with highly disruptive potential.
- It is expected to aid in supply chain digitalization by enabling end-to-end transparency and facilitating trust between different parties.
- There are yet to be successful implementations due to the lack of know-how on its application and use in the supply chain.
- There is a lack of blockchain research dedicated to its use in supply chain applications.

There was no identified framework, architecture or tool that have grouped together the current knowledge on blockchain and how to apply it in the supply chain. These facts were highlighted by an initial literature analysis and further supported by interviews with industry experts. To solve this problem, eight research questions were designed, in table 1-1, the findings of which are discussed below.

6.2.1 Findings to thesis research questions

RQ1: What is blockchain technology and what are its main application benefits in the supply chain?

The lack of knowledge surrounding blockchain technology is one of the main identified barriers to adoption. The first research question was thus to clarify what blockchain is and to identify its advantages for the supply chain. Blockchain is a type of Distributed Ledger Technology. DLT's involve a shared transaction database which is updated by computerized consensus, has timestamped records and provides a tamper proof auditable history of all ledger transactions. In blockchain, new transactions are grouped in blocks which are cryptographically linked to one another forming a chain of continuously updating transactions. The cryptographic hashing of blocks, combined with computational constraints and incentive schemes for block creation, results in an immutable record of transactions which can contain money, assets or information.

The unique value proposition of blockchain is that it can maintain a trusted ledger between a network of individuals who do not necessarily trust one another, all without an intermediary or central authority. This has significant benefits for supply chains where products move between a network of companies, often plagued by issues surrounding trust and transparency. Blockchains' immutable ledger provides a method to enhance trust, transparency, visibility, security and automation of information flows, which ultimately leads to reduction of costs, complexity and errors in the supply chain.

The research question was answered by findings derived from a literature analysis. It was found that there is still no formal definition of blockchain and most descriptions focus on Bitcoin's proof-of-work blockchain. In reality there are many different types of blockchains with various structural and performance characteristics.

RQ2: What are the latest technological architectures of blockchain technology?

In order to determine the different blockchain structures, the second question aimed at identifying blockchains' latest technological architectures. A technical examination of blockchain revealed that there are many different types of blockchain architectures and configurations, all of which influences factors such as performance, security, scalability, trust, efficiency and operation. These technical aspects are its mode of operation, platform, consensus method and architecture.

Public blockchains allow anyone to join the network whilst in a private blockchain, members have to be pre-approved. This allows for more control over privacy but removes the incentivised trust aspect of public ledgers. Hybrid ledgers seek to combine the privacy controls of private blockchains with the immutable trust of public blockchains for improved scalability.

Consensus mechanisms are algorithms that uphold the integrity of the network by determining how nodes reach consensus on the validity data. Different mechanisms were identified, such as PBFT, POW & POS. It was found that faster and more efficient consensus mechanisms are generally less secure, whilst robust and secure mechanisms were more resource intensive and slower. Performance and security are the two current trade-offs when it comes to reaching consensus.

Hyperledger (private) and Ethereum (public) are currently the two most popular and usable enterprise ready platforms. Hyperledger is maintained by a consortium of companies aiming for easier integration with existing business processes whilst Ethereum is more generic and open source. Many new platforms use a modified version of Ethereum for increased scalability and performance. One such example is Quorum blockchain (hybrid) which provides enhanced control of privacy for increased business scalability.

There is currently no clear indication which platform or technical architecture is best suited to supply chains as each offers a different set of advantages. Whilst Ethereum and Hyperledger are the main platforms for supply chain uses, there are many other new platforms in development that aim to improve scalability. Further research, development and implementations are needed in order to determine the best technical solutions.

RQ 3&4: What are the latest challenges in supply chain digitalization and tracking and tracing; how can blockchain enable tracking and tracing in the supply chain?

In order to understand the need for blockchain technology in the supply chain, the third and fourth research questions were asked to determine current challenges in supply chain digitalization and how blockchain tracking and tracing could address them.

Current supply chains contain a combination of paper-based and digital processes with no end-to-end process integration. IT infrastructures are isolated, which hinders party-to-party information sharing resulting in issues such as lack of trust, agility and transparency. This makes it difficult for supply chains to perform tasks such as verifying a products' origin or characteristics. Trust and transparency are key requirements of digital supply chains. A change in consumer behaviour has resulted in an increased focus on claims made regarding the health and environmental implications of products. Health scandals and disease outbreaks in food supply chains have highlighted that companies are ill equipped to track and verify the origin and characteristics of products.

Tracking and tracing is a key capability of supply chain digitalization. It involves the ability to securely record product information, allowing different actors to verify the history, location or characterises of that product anywhere in the supply chain. Traditional non-blockchain track and trace methods are fragmented, require high levels of trust and do not effectively communicate data throughout the supply chain. To trace back the history of a product is a lengthy and complicated process. Blockchain has the capability to significantly reduce the time and complexity of tracking and tracing. This has been supported by early case studies where a products' history could be traced in a matter of seconds as opposed to days. Tasks supported by blockchain reduced delays and administrative processes.

Blockchains' ability to keep an immutable ledger of transactions across a network of untrusted participants provides a unique value proposition that addresses the problems faced with current track and trace systems. Blockchain will act as an application layer, that stretches over existing process and IT systems in the supply chain. This provides an opportunity to break down the existing 'siloed' structure and create an information ecosystem.

Using technologies such as IoT, a products' physical identity can be digitized and linked to a blockchain transaction. As products move between parties in the supply chain, data regarding its location, content, quality, characteristics or origin is shared to the blockchain ledger. In this way, the entire history of a product can be stored providing abilities such as provenance and certification of authenticity.

RQ 5: What use cases exist for blockchain in the supply chain, specifically related to tracking and tracing?

Research question five seeked to identify blockchain case studies in the supply chain in order to obtain an overview on current developments. It was found that current use cases in the supply chain centre around tracking and tracing, especially in food supply chains. The main benefits, sought by companies using blockchain, are end-to-end transparency, enabling abilities such as providing provenance, authentication and validation of product claims. Case studies predominantly use Hyperledger and Ethereum platforms, with more in favour of private blockchains for enhanced privacy controls. These case studies, however, are not fully implemented real world solutions. They are mostly small scale pilot projects in controlled environments. There is yet to be a real world end-to-end supply chain blockchain solution.

The semi structured interviews with industry experts confirmed these findings. Successful industry uses are rare. Experts and companies do not yet fully understand blockchain. This is because the technology is still evolving and improving. It is difficult to sell a technology that people do not understand. The human factors, are thus one of the important limitations that need to be overcome in order to further successful implementations.

RQ 6 & 7: What are the various blockchain design requirements, and how can a reference architecture be designed to support the development of blockchain in the supply chain?

A design reference architecture was found to be a key tool in furthering blockchain understanding in the supply chain. Reference architectures encapsulates both the technical, social and business/logical components. It acts as a model or framework which describes the different activities that should be performed, tools/methods available and procedures to follow. The design reference architecture in this thesis provided generic design guidelines, requirements and considerations for the use of blockchain in the supply chain. It serves as a guide that can be consulted to support teams in the design of blockchain track and trace systems.

By extracting the relevant blockchain design requirements from blockchain frameworks, case studies and technical research, an architecture was designed that included the strategy, feasibility, product, supply chain and technological design components for blockchains use in supply chains. Each of these sub-architectures contained a set of important guidelines and considerations.

- Strategic requirements focused, amongst others, on the important leadership guidelines which addresses the important human component in blockchain adoption. It was found that supply chain wide digitalization is important to ensure that the required enabling technologies are in place to form an information ecosystem.
- The feasibility section presented a set of 15 questions that can help determine whether a given use case is suited for blockchain technology. This directly addresses the problem of identifying the right cases where blockchain will add the most value.
- The product architecture focused on forming a case around the right product. It found that any product making a specific value adding claim is aligning itself for blockchain technology. It is important to identify the right products facing transparency problems and identifying the key characteristic that is of value to its identity.
- The supply chain architecture provides important guidelines surrounding supply chain processes and the stakeholders involved in the blockchain network. It is important to identify which processes or tasks blockchain will add value to and what information transactions occur on the network. There needs to be alignment of interests between the right stakeholders and each stakeholder needs to understand the benefits that such a solution will provide. This section identified many other important guidelines relating to governance, 3rd parties, performance and trust.
- The technology architecture is key as it clarifies the decisions surrounding blockchain technology. It is important to first establish the data requirements and identify what the various data flows are in the supply chain and how accuracy and security of data entry is achieved. Blockchain should be capable of interacting with existing IT systems and not replacing them. Regarding the blockchain design decisions, it is important to consider the deployment architecture, mode of operation, consensus mechanism and platform as this will dictate how blockchain will deliver value.

RQ 8: Would such an architecture provide sufficient guidelines for design teams to develop blockchain based track and trace solutions in the supply chain?

The design reference architecture that has been constructed, provided a collection of important guidelines across technical, strategic, feasibility product and supply chain aspects on how to approach the design of blockchain systems. A case study along with semi structured expert interviews provided a multi-dimensional analysis of the architectures validity.

There was a resounding consensus between the experts that the design reference architecture was practical, applicable and useful in addressing the problem stated. The reference architecture:

- Formalized a collection of knowledge to advance understanding and application of blockchain in the supply chain.
- Provided a comprehensive summary of all the important aspects involved in a blockchain track and trace endeavour.
- Aides in more efficient decision making and in feasible use case identification.

The results generated motivated that the design reference architecture achieved its aims. The case study application further demonstrated that the reference architecture can be applied in a real world scenario and be found useful by teams developing blockchain track and trace solutions.

6.2.2 Importance of findings

The importance of this design reference architecture was indicated through the validation process. The case study application found that a current lack of know-how on blockchain resulted in wasted time, money and effort in identifying and designing the correct use cases. There was no formal grouping of guidelines or any frameworks that aided in highlighting the important decisions. The feedback received motivated that this architecture would aid identifying the right decisions and requirements. It would have saved time and enhanced application knowledge had they used it from the start. Further, in the industry interviews, it was found that there is a definite need for a reference architecture to support the design and development of blockchain implementations.

This reference architecture is the first to group the important aspects together and make it easily understandable. These findings confirm the validity of the architecture and provide a motivation for the fact that it has achieved its stated aims.

6.2.3 Conclusion on the design reference architecture

In chapter three, a design reference architecture was defined as a reference architecture representing the different design principles, best practices and guidelines that can be consulted to aid the development of information systems. It is used to improve decision making, and serves as a guide to support engineering teams involved in the design of an enterprise or system. It is more detailed and provides a better methodology in comparison to a framework.

Based on the validation done, the design reference architecture fulfils this definition. It was proven to aid decision making, and provided comprehensive guidelines regarding blockchain technology in the supply chain. It fulfilled the methodology component by providing a practical approach to consulting the different sub-architectures.

It answered the main research questions by providing a literature study, methodology, design and practical validation, of a blockchain specific design reference architecture supporting track and trace applications in the supply chain. It thus contributes to the research gap on blockchain technology, and furthers the development of its use in practical supply chain applications.

6.2.4 Conclusion on the topic of blockchain in the Supply Chain.

Since the start, blockchains' promise has been about revolutionizing and disrupting supply chains. Most people have been introduced to this topic by the promising claims and high levels of hype/press surrounding it. After completing this master's thesis, there are a few important questions and factors that need to be answered in order to evaluate the current state of the blockchain supply chain.

Will blockchain have a major impact on the supply chain? Based on the research done, case studies evaluated and interviews conducted, almost undoubtably yes. Blockchain delivers unique and significant value that cannot be equalled by traditional systems. This said, there will be specific cases where blockchain will be suitable and add value. It is not a solution to all problems as proclaimed. These suitable instances need to be identified in order to avoid disappointment.

Will blockchain be cheaper, faster and easier as claimed? Based on the current state blockchain development, no. We are at the early stages of blockchain. Poor understanding and lack of supporting technologies will imply that implementing blockchain today will be a complex, slow and expensive endeavour. The most appropriate use cases, implementation methods and technology choices remain elusive.

Scalability is still a major problem. Companies are looking towards permissioned/private blockchains to solve that issue. However, a private blockchain is opposed to the very open and transparent nature that unlocks the true value of blockchain. The owners(s) of private blockchains could dictate the network's structure and operation, which would make blockchain no different to a traditional centrally controlled system (apart from the fact that its more expensive). Blockchain needs to remain true to its original purpose – trust. The only way to achieve that would be to distribute the validation nodes between a large network of diverse participants with different interests. To achieve the benefits of decentralized trust, the trust must primarily be – decentralized. Through this, the true promise of blockchain is realized and in that case, it can actually make a significant difference.

Technological advances in the next few years will improve its scalability. The technical hurdles of today will be non-existent in the coming years. The question is not '*if blockchain will revolutionize the supply chain'* but '*when*'. It is thus imperative that today's supply chains develop and understand blockchain tracking and tracing. When the first successful real world implementation comes into existence, adoption across industry will be rapid.

The biggest hurdle yet to cross is the human element. Supply chain decision makers have long been opposed to open and decentralized systems. Success of this technology can only be guaranteed when the understanding is driven that '*in a blockchain network, everyone wins when trust is decentralized'*.

6.3 Research contribution

Table 6-1 provides an overview of the different academic and practical contributions made by this research. The original problem is that companies in the supply chain are struggling to successfully implement blockchain technology. It was identified that there is a lack of blockchain research that focuses on applications such as the supply chain. The specific research gap was that there was no reference architecture for the application of blockchain in the supply chain, specifically with regards to track and trace implementations. The main contribution was thus the formulation of a design reference architecture that can be used to guide teams on developing blockchain tracking and tracing in the supply chain. This would address the current research gap and would aid companies in the development process of successful blockchain implementations.

Table 6-1 Research contributions

	Academic	**Practical**
Contribution	- Furthered application-based research & increased knowledge on blockchain technology in the supply chain. - Identification of the important design requirements and considerations for blockchains' use in supply chains. - A research tool (Reference Architecture) that logically groups the important design guidelines and requirements.	- An architecture that can be used as a reference to help guide supply chain professionals and companies who are considering the implementation of blockchain technology. This tool can be consulted to help clarify the various design guidelines, requirements and considerations needed. - A set of considerations and design guidelines that can be used as a basis for blockchain business plans, decision making and implementations.
Benefactors	- The academic community focusing on furthering application based knowledge and research on blockchain, specifically within supply chain track and trace environments.	- Supply chain companies and professionals who are considering or in the process of designing blockchain solutions. Executives and decision makers who wish to gain a better understanding on the various factors involved.

6.4 Research limitations and recommendations for further research

6.4.1 Limitations

Blockchain research in the supply chain is less than five years old. Its complexity and wide scope of study resulted in a few limitations being introduced at the start of the study. Although they are limiting factors, their purpose was to help keep the focus of the thesis on the main problem. They stated that the project would not include:

- The consideration of other DLT technologies besides blockchain.
- The aspect of tokenization and cryptocurrency.
- An in depth technical analysis and comparison of blockchain architectures.
- Other types of supply chain uses such as smart contract financing, for example.

Although they would not have supported the main problem they are still relevant to the application of blockchain in the supply chain. They are thus topics that should be explored in future research.

The main limitation of this study was that it did not encompass a practical implementation of blockchain in the supply chain. The reason that this was not done was because the application of the technology to the supply chain was in a too early stage to properly motivate this procedure. Although practical implementation knowledge would have been gained, it would not have addressed the main research gap. Also, experts are not sure on the best methods of conducting a practical application. Thus, for it to make sense, many different applications will have to be done using different technology platforms, consensus mechanisms and architectures in order for it to provide valuable and usable results. The design reference architecture presented in this thesis can be used as a basis for developing practical applications after which an implementation guide can be properly generated.

Another factor that is perhaps not a limitation but something that should be taken into consideration is the rapid pace of blockchain development. Blockchain is only 10 years old and over the last 2 years of conducting this thesis there have been numerous new platforms, ideas, innovations, solutions and use cases. Blockchain problems surrounding privacy and scalability that were made clear in research papers of 2017 and 2018 have since been solved in 2019. The pace of innovation is moving much faster than the pace of academic blockchain research. Many of the current limitations and barriers listed in this study are expected to be addressed in the next few years.

6.4.2 Recommendations for further research

The points below highlight potential future research that is relevant to advancing blockchain's application in the supply chain:

- Development of an implementation framework or architecture. An implementation guide will provide detailed steps, in sequence, on the correct tasks and procedures that must be done to apply blockchain in the supply chain. Such a guide can be based on this design reference architecture. However, there needs to be more practical case studies and successful implementations in order to generate this guide.
- In depth comparison between the needs of supply chain management and blockchain platforms/architectures. The blockchain design reference architecture lists and compares the

different platforms and technical aspects, however at this stage it is not possible to recommend one over another. In order to generate recommendations on which platforms and architectures to use, an in depth technical analysis must be done according to the needs of supply chain tracking and tracing.

- Research on possible blockchain business plans containing information such as cost aspects. This was one need that was suggested during the expert validation stage of this project. A study on the cost of blockchain implementation and business aspects of it would be of benefit.
- One of the challenges identified through the semi-structured interview process with industry experts was that companies are not yet ready to place their trust in the system. They are not comfortable with the idea of decentralization, sharing data and placing trust in blockchain and IoT. A research question that can thus be asked: '*How do you get people to trust the system*?' This would target the specific problem of change management in relation to blockchain adoption.

Chapter 7 References

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Appendix A

The appendix contains additional information, not essential to the main body of this thesis. The goal of the study was to keep the appendixes as short as possible, by including the most of the essential information in the main body.

A.1 Semi-Structured Interview Guide

The interview guide was used to help conduct the expert feedback interviews in the second part of the validation process. The general guide is presented below.

1. Introduction

Introduce myself (the author). Explain the background and overall purpose of the study. Present a clear overview of what is expected from the expert and how his/her responses will be used.

2. Ethical considerations

Clarify and make the expert aware of the various ethical considerations that have been taken into consideration.

3. Expert background and experience

Ask the experts about their background and experience in blockchain technology and the supply chain.

4. Presentation of design reference architecture

Present the design reference architecture in this thesis, explaining each sub architecture and the accompanying research findings.

5. Feedback on design reference architecture

The expert provides feedback on each specific sub-architecture and guideline. Thereafter he evaluates the overall architecture based on its:

- Content validity
- Applicability and use
- Practicality

6. Recommendations

The expert suggests possible improvements and recommendations for the architecture.

7. Knowledge/opinion based on industry experience

The expert is invited to give his personal opinion on the current state of blockchain in industry and what current problems they are dealing with. They can also motivate if this study could address current issues experienced and how it can be used in practise.

8. Closing

Present a summary of the feedback received during the session. Thank the expert for his/her time.

A.2 Ethical considerations

Data collected will be comprised of feedback in relation to the results of the case study analysis as well as expert feedback from industry experts on the validity and practicality of the reference architecture developed. During the interview, notes will be taken based on the participant(s) feedback on the Design Reference Architecture. These notes will be typed up right after the interview for use in the validation section of my thesis. If requested the notes can be shared with the participant to ensure that all information listed is correct. The document is stored on a secure iCloud drive that only the author has access to. No names of participants will be used nor will any personal information be gathered that can be used to identify the participant. Information collected is expected to be of low or minimal risk as it does not involve personal information, does not cover a controversial topic, does not contain sensitive/classified information nor would it cause harm if improperly used.

The participants in the interviews will be informed that any information shared that could identify them as a participant will be protected. This will be insured as follows:

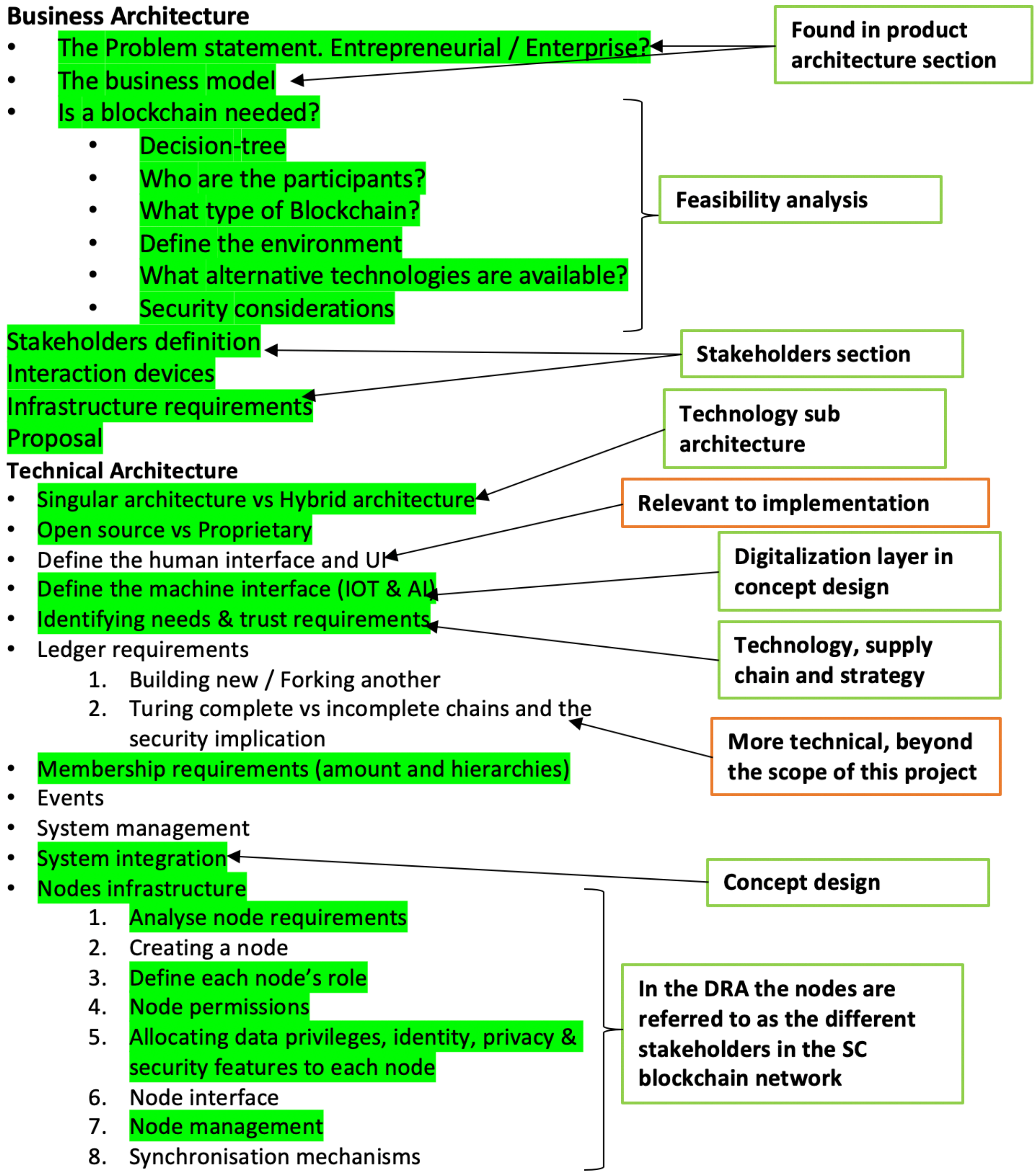
- Not recording the names of the participants involved in the interview or tying them to the information gathered.
- Not sharing the information with anyone outside of those involved in the study.
- My research will also not include any direct quotes or personal identifiers.
- Storing all data gathered on a password protected folder secure password-protected laptop which only the student has access to.
- Participants will have the right to review all the information gathered during the interview and approve it for use in the study.
- Any mention of the data gathered from the interview within the study will ensure full anonymity to both the participants, their department and the company involved.
- Participants can at any time opt-out and refuse for their information to be shared
- The information collected is only intended to be used for this study alone and is not intended to be used for any future research or purpose.
- The participant(s) contact information, used for arranging the interview, will not be used in the study and is stored on a secure device that only the student has access to.

The case study was set up with a partnering company. The company is a large international FMCG supply chain company currently running a blockchain pilot program on one of its supply chains. In this collaboration an authorized individual from the company gave the author access to supply chain data that is not linked to any individual or contains any personal information or sensitive information. This process was governed by an NDA agreement through the company and Stellenbosch University.

Other data was collected by method of structured interviews with individuals in industry. This data was used in the validation of the architecture. Ethical clearance was granted by Stellenbosch Universities ethics committee and the project was classified as low risk.

A.3 Suggested Blockchain Architecture Components

The blockchain technology consulting and developing expert supplied a list of architecture components collected from the experts experience in the industry. These components can be compared to the DRA developed by the author. It must be noted that the architecture components are more focused to the technical development side of blockchain and applicable to financial and insurance applications. They are thus not specifically aimed blockchain in the supply chain. However, they can still be used to obtain a general idea for a comparison. The architecture components are listed below. The author has supplied comments based on the inclusion and exclusion of the various requirements.



- Blockchain structure
    1. Blocks & headers (Standard Block model / Simple Block Model)
    2. Block times
    3. Propagation & internode communication mechanisms
    4. Provenance, immutability & finality
- Consensus & validation Mechanisms
    1. Determining trust requirements
    2. Evaluating available consensus mechanisms
    3. Consensus vs trust requirements vs node amount vs users vs settlement times vs finality vs throughput vs security
    4. Transaction costs
- Wallets & Storage
    1. Hardware vs Software wallets
    2. Cold / Hot storage philosophy
    3. Memory dumps
- Developing and operating costs
- Risks: Enterprise, operational, geopolitical, market, reputational, systematic, compliance, third party.
- Interoperability & Integration
- On-chain vs off-chain functions
- Second layers
- CoCo framework
- Smart contracts
- Multisignature
- Compliance
- Support

Discussed in literature review however not relevant to architecture

Technology Architecture

More specific to the financial side an technical operation

More suited to business and financial model

Technology Architecture

Beyond the current scope of the supply chain reference architecture

- Chaincode
    1. Immutability of code
    2. Blockchain interoperability
    3. Integration with traditional software apps
    4. Integration with connected devices
    5. Securing of data feeds
- Cryptography requirements
- API sets
- Servers
- Security philosophy
    1. Security implications for Geth, BitcoinD, Parity & Dash Core
    2. Firewalls
    3. Latency liabilities
    4. Solutions: OpenTimetables, Credits, Hyperledger, Stellar

These aspects are more on the development side of blockchain thus outside project scope

k. Support

Security & Implementation of large scale solutions

- Project Management A-Z
- Juridical matters
- Regulation
- Security loopholes
- Defining project goals
- Success / Failure Metrics
- Adoption
- Risk Management

Proof of Concept

- Building the pilot

The Hybrid Blockchain

Technology sub architecture

- Best of both Public Permissionless and Private Permissioned chains
- Integrating the networks & Technical workflow

Developing

- Open source vs Commercial Development Platforms
    1. BigChainDB
    2. Elements Blockchain Platform
    3. Eris:db
    4. Multichain
    5. Openchain
    6. Quorum
        I. Additional consensus with Quorum
        II. How Quorum achieves Privacy and private states
        III. Quorum altering and extending Web3
        IV. Deploying a local and cloud (Azure) Quorum network
    7. Sawtooth Lake
    8. Stellar
    9. Chain Core
    10. Corda
    11. Credits
    12. Domus Tower Blockchain
    13. Ethereum
    14. Hydrachain
    15. Hyperledger
    16. Symboint Assembly

Development & hosting resources
1. Which skills are needed
2. Transferable software development skills

- Critical considerations before a project is commenced
- The importance of language interoperability
- Strengths & Weaknesses: C++, C, JavaScript, Java, Python, Go, Solidity, NodeJS, Kotlin

Technology sub architecture

As noted in the theory, there are a plethora of blockchain platforms in existence. This study focus on those applicable to supply chain and that have been proven in existing case studies. Other platforms listed here are notable but have not been proven in supply chain track and trace.

Technology sub architecture

Outside of project scope