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Exploring the use of Permissioned Blockchain Technology for supply chain Traceability

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MASTER'S THESIS

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Abstract

Blockchain is a form of Distributed Ledger Technology (DLT) that is known to us with the success and adoption of Bitcoin. Earliest examples of ledgers used for account keeping dates back to 1000 years in Europe and the concept of ledgers is well known to mankind. Blockchain implements ledgers that are shared and stored in a decentralised and distributed manner. People use banks as they trust them with the money and similarly in supply chain networks, organisations preferably conduct trade with trusted partners and intermediaries. The use of Blockchain eliminates the need for trusted third parties as it provides one version of the truth to all participants in the form of an immutable data trail. The emergence of Blockchain technology also coincides with the soaring demand for transparency and fair trade practices; However, consumers have no means to verify the information present on product labels which adds to their uncertainty. This research shows how Distributed Ledger Technology can be applied in supply chains offering consumers the means to verify product traits. So the question is whether the use of permissioned blockchain could bring transparency and end-of-end traceability of products in current opaque supply chains by allowing consumers to verify provenance and product traits. Moreover, this research identifies the problems associated with opaque supply chains and how blockchain may provide solutions to some of these. The research further investigates a permissioned blockchain solution in the form of Hyperledger Fabric. As a result, a theoretical system is proposed which provides understanding for creating proof of concepts in supply chains.

Abbreviations

E1 to E4: Symbols to denote experts used for collecting data.

FTO - Fair Trade Organisation

.bna - Business network archive in Hyperledger

MSP - Membership Service Provider in Hyperledger

NFC - Near Field Communication

P2P - Peer to Peer

POW - Proof of Work

POC - Proof of Concept

PKI - Public key infrastructure

POS - Proof of Stake

RFID - Radio Frequency Identification

RQ - Research Question

SCM - Supply Chain Management

TPB - Theory of Planned Behaviour

UI - User Interface

WFTO - World Fair Trade Organisation

Chapter 1. Introduction

Nowadays blockchain has become quite the buzzword both in the industry as well as the academia. Blockchain is nascent and emerging information technology in 2018 with a lot of potential and hype around its use. It gained popularity as the underlying technology behind the digital asset Bitcoin which started functioning ten years ago. In recent times though, Blockchain is seen much more than facilitating the exchange of digital cash, as smart contracts have opened up a whole heap of use cases beyond digital currency. The consumer supply chains are one area where Blockchain technology is seen as a solution to facilitate transparency of processes along with traceability of goods, and this paper shows how the technology is put into practice along with highlighting benefits as well challenges of deploying Blockchain technology in supply chains.

1.1 Research topic

The topic for this research is the use of Blockchain Technology in Supply Chain Management (SCM) to achieve traceability of products and transparency in consumer supply chains. In this thesis, the researcher wants to explore how supply chains can be made more transparent, trustworthy and audit-able using the inherent characteristics of Blockchain technology. The nature of this research is exploratory.

1.2 Supply Chain

In the most simple words, a supply chain is a collection of the functions involved in creating a finished product and delivering it to the end consumer. It is a complexly interconnected network comprising of many actors. Various products we consume reach us through a network of supply chain participants. From the point of view of Beamon (1998: 281), "*a supply chain may be defined as an integrated process wherein a number of various business entities (i.e., suppliers, manufacturers, distributors, and retailers) work together in an effort to: (1) acquire raw materials, (2) convert these raw materials into specified final products, and (3) deliver these final products to retailers*". Lummus et al., (1999: 1) have also given us a definition by analyzing various views on supply chain in the literature and industry as: "*all the activities involved in delivering a product from raw material through to the customer including sourcing raw materials and parts, manufacturing and assembly, warehousing and inventory tracking, order entry and order management, distribution across all channels, delivery to the customer, and the information systems necessary to monitor all of these activities*". Supply chain management aggregates all these activities mentioned above into a single seamless process as explained by the authors. The authors also made a critical distinction that all the entire process flow must be viewed as one system, and the goal of such a system is to stay competitive in the relevant market.

It is also clear, Information Systems are essential for supply chain management, and these systems rely on information flow from all activities in a supply chain. Consistent and correct information increases traceability of products in complex supply chains. Traceability of products is also dependent on the identifiability of raw materials used in finished products. Failure to identify traceability information makes supply chains opaque. Benefits of traceability include food safety and reduction in the impact of recalls on public health. Traceability is also the means for efficient supply chain management which further adds to the competitive advantage of brands.

1.3 Fair Trade

The concept of Fair Trade has gained worldwide popularity, and global sales of fairly traded products reached €7.88 billion in 2016, which benefited 1.6 million farmers across the globe **[2]**. To understand what Fair Trade is, let us look at an accepted standard definition retrieved from the World Fair Trade Organisation (WFTO) **[3]** :

"Fair Trade is a trading partnership, based on dialogue, transparency and respect, that seeks greater equity in international trade. It contributes to sustainable development by offering better trading conditions to, and securing the rights of, marginalized producers and workers – especially in the South. Fair Trade organisations have a clear commitment to Fair Trade as the principal core of their mission. They, backed by consumers, are engaged actively in supporting producers, awareness raising and in campaigning for changes in the rules and practice of conventional international trade."

Farmers are at the forefront of food chains; however, they are considered insignificant in the value chain, as other stakeholders take the majority of profits. The WFTO is a network of global organisations working towards a common goal of a more sustainable and fair global economy thus improving the living conditions of producers. WFTO ensures its member organisations abide by the principles and criteria set by the WFTO. Fair Trade member organisations buy from certified producers, and by doing so, member organisations can display a fair trade label on their products which lets the consumer identify fairly traded products. The model ensures that suppliers and producers are paid fairly. The model also consists of regular audits to ensure compliance from producers. One of the certifications providers for WFTO is FLOCert, which monitors fair trade compliance of supplier, producers and traders. The standard operating procedure for certification applications **[4]** and audits **[5]** can be found on FLOCert website.

1.4 Blockchain Technology

Although different definitions of blockchain exist, at its essence, a blockchain is a single shared transparent ledger of confirmed transactions, organised in blocks and stored on a peer-to-peer network chronologically and permanently. Cryptographic techniques are at the core of blockchain technologies due to which blockchain is considered to be more secure than databases used currently. The ledger is immutable, and once the transactions are appended to the chain, transactional data becomes tamper-proof. Due to the peer-to-peer nature of the technology, the system is not managed centrally by an individual entity; and this also requires every peer to agree on the validity of a transaction which is achieved by a process called consensus. Although various types of algorithms are used to achieve consensus in a blockchain network, in a nutshell, the role of a consensus is to agree on the order, correctness and validity of transactions amongst the peers.

The first every blockchain system for peer-to-peer transfer of Bitcoin was created by Satoshi Nakamoto (pseudonym) and the abstract of his paper (2008: 1) states, "*Digital signatures provide part of the solution, but the main benefits are lost if a trusted third party is still required to prevent double-spending.*" Therefore a key aspect of blockchain to note here is that blockchain fundamentally removes the need for trusting a third-party, by placing trust on cryptographic proof. The participants on Bitcoin blockchain can initiate and verify their transactions without the need of any mediator.

Moving on from the use case of digital cash transfer, other use cases of blockchain systems have emerged with the introduction of smart contracts. A smart contract is a chunk of code that executes once the conditions specified in the code are fulfilled. The use of blockchains also brings many advantages to supply chain networks where transactional information is often fragmented and inaccessible by all participants. Traditionally participants maintain their data with centralised systems and rely on third parties such as banks and logistics providers to confirm transactions and movement of goods. Blockchain enhances efficiencies of a supply chain network with near real-time data flow and adds more visibility to supply chain goods.

1.5 Problem statement

Labels on food products show us regulatory information mandated by the government; however, there's no way we can verify the information on the label of a product we buy. Consumer perceptions show increasing concern about food safety and the information available from labels does not always translate into more confidence (Aung & Chang, 2014). Similarly, Fair Trade labels are a way of identifying and buying fairly traded items, yet these labels do not provide consumers with a way to verify the provenance of a product, its value chain and compliance to mandatory and claimed standards. Consumers have to rely on the guarantee of Fair Trade organisations by just looking at the Fair-Trade sticker. The techniques used by NGOs to monitor Fair Trade compliance are referred to as "antiquated techniques" by Kshetri (2018: 87). Product compliance is determined on some form of on-site manual audit based on a complaint or scheduled per year. There is an apparent need for means to verify product claims made in food chains and fair trade networks.

1.6 Research gap & statement

Blockchain is a new technology, and Tian (2016) notes immaturity as a limitation of current public blockchains for use in SCM, citing an example of limited throughput (7 transactions per second) which makes public/permissionless blockchain infeasible for supply chain management. Furthermore, blockchain based supply chain solutions developed in the field currently showcasing successful proofs-of-concept, namely PROVENANCE and Walmart (Kshetri, 2018), are proprietary and closed source solution offering no contribution to the research. Hence we are unable to see the advantages and potential of the technology which limits the adoption of technology in the industry (Galvez et al., 2018). While supply chain management is described as a potential use case of blockchain technology theoretically in many papers, there is no evaluation of actual benefits and barriers in practice.

Besides a research gap is identified in the understanding of whether or not blockchain-application is relevant to provenance certification of supply chains. This research can be based on the theory of planned behaviour, which links behaviour to intention. A consumer may show positive intention towards traceable products; and may be interested in verifying safety, origin and characteristics of food products. Ajzen (1991) notes when a person has a positive intention but fails to act on the intention, the failure is attributable to the person's perceived control over the behaviour. Lack of resources and opportunities available to a person reduce the likelihood of behaviour to some extent as it impacts actual control of a person in performing a behaviour. Lack of trustworthy information available for verifying product traits hampers the decision to buy similarly.

Based on the research gaps and problem statement mentioned above, the use case of traceability and certification of products in a supply chain is presented in this research thesis, highlighting the benefits of permissioned blockchains for businesses in SCM, its challenges and design for implementation in banana supply chains. This research will investigate whether or not a permissioned blockchain system can give consumers the opportunity to verify the provenance of bananas, along with Fair Trade and organic traits of bananas by storing information on blockchain that serves as proof. By providing an opportunity to verify product traits with immutable data on the blockchain, the research aims to enhance a consumer's perceived behaviour control, which would consequently result in positive buying behaviour as per Theory of Planned Behaviour. The following overarching research question followed by sub-questions are formed as a result.

How can we achieve end-to-end traceability and transparency in banana supply chains along with creating verifiable certifications of Fair Trade and organic bananas with the use of permissioned blockchain technology?

1. Is blockchain effective in tracking products all along the supply chain?
2. What are the advantages of using blockchain technology in supply chains?
3. What are the advantages of using a permissioned blockchain technology in supply chains?
4. How can blockchain technology be implemented in supply chains?
5. What are the incentives for stakeholders to use blockchain technology for supply chain management?
6. What are the barriers and challenges in adopting blockchain technology for supply chain management?

1.6 Research relevance

From a societal standpoint, tracking a source of contaminated food is of primary importance in food chains as it affects people's health simultaneously damaging their trust in the food market (Tian, 2016), and for this reason, the food industry is most likely to be revolutionised by the use of blockchain technology. An incident of the E.coli virus outbreak at Chipotle Mexican grill left 55 customers ill (Kshetri, 2018). From the perspective of a consumer, supply chain traceability helps to build trust and increase confidence in the food system (Aung et al., 2014). Supply chains are often opaque, as consumers do not have a way to verify the provenance and compliance of food products. The perishable food items in a supply chain change hands with many actors before it gets to a customer and the quality of these items depends on how food products are handled at every touch point (Aung et al., 2014). The ability to collect real-time information in a supply chain provides tangible benefits and reduces the impact of unsafe food. The use of blockchain is seen as a solution to track food items and verify social sustainability claims as explained Kshetri (2018).

Not knowing about the provenance of consumer products creates uncertainty about their safety, quality, value and compliance. This uncertainty also leads to perceived risks which play a part in shaping the buying behaviour of a consumer. Perceived risks can alter a customer’s purchase intention and as put by (Kotler et al., 2016), and are categorised as *Functional risks* associated with the functioning of products as per expectations of the customers. Physical risk of harm to one's health or physical well-being. For example, consuming contaminated food can cause health problems. The *financial risk* of losing the money associated with the sale or paying an unfair price for the product which is not worth its price. *Social risk* is the one which produces embarrassment in a person's social circle as a result of making a purchase. *Psychological risk* happens when a product affects the mental well-being of the buyer. *Time risk*, when a product fails soon after the purchase which leads to the consumer buying alternative products.

Interestingly any guarantee offered by the companies regarding their products reduces buyer's perceived risks. In line with the work of (Kahneman, 2011) in decision making, it is also interesting to note that in a profit or value seeking situations, we human beings, tend to make choices that are risk-averse. The same is true for buying decisions that tend to be risk-averse. The use blockchain could potentially reduce risks for consumers as buyers can see tamper-proof provenance and handling information of products which can be verified upon purchase.

From an industry point of view, supply chains are complex and non-integrated. A recent poll by Deloitte found out 31% of the respondents have experienced supply chain fraud in the past 5 years [9]. Every stakeholder in a supply chain network maintains their information systems centrally and traditionally these systems do not speak with each and therefore supply chains are subject to fraudulent behaviour. Traceability systems are an essential element in meeting supply chain objectives and gaining consumer trust particularly in the food industry (Aung et al., 2012). The use of blockchain also leads to a better competitive advantage as it reduces inefficiencies in a supply chain along with enhancing consumer trust with a secure way to store information.

1.7 Research outline

Chapter 1 introduces the research to the readers along by outlining definitions of blockchain, supply chain and fair trade which are central to this research. The chapter also provides an understanding of the research topic and the objective of this research.

Chapter 2 lays a theoretical foundation by explaining the theory of Planned Behaviour first and the concepts of Blockchain technology along with supply chain traceability identified from the literature.

Chapter 3 outlines the methodology for qualitative research undertaken for answering the research questions. The chapter also explains how data is collected and analysed.

Chapter 4 & **Chapter 5** present a critical review of the literature on blockchain and the use of blockchain in supply chains. Requirements for achieving traceability are established in this chapter with the help of scientific papers. Problems found in supply chains and opportunities are also listed here along with identified sources.

Chapter 6 looks at the means of providing traceability systems and outlines the technical implementation of permissioned blockchain in banana supply chains, presenting the use and description of Hyperledger Fabric. Such a system allows consumers to verify provenance and traceability of their products.

Chapter 7 concludes the research by answering research questions, and **Chapter 8** presents a discussion of important themes identified during this research, along with limitations and suggestions for future research.

Chapter 2. Knowledge Base

This chapter lays a theoretical foundation for this research with the help of published literature in the field. Theoretical concepts relevant to the research are presented starting with the Theory of Planned Behaviour (TPB) which can be used to understand buying behaviour of consumers by linking it to intention. The chapter also expands the understanding of blockchain technology by explaining the fundamental concepts of blockchain from the theory.

2.1 Theory of Planned Behaviour (TPB)

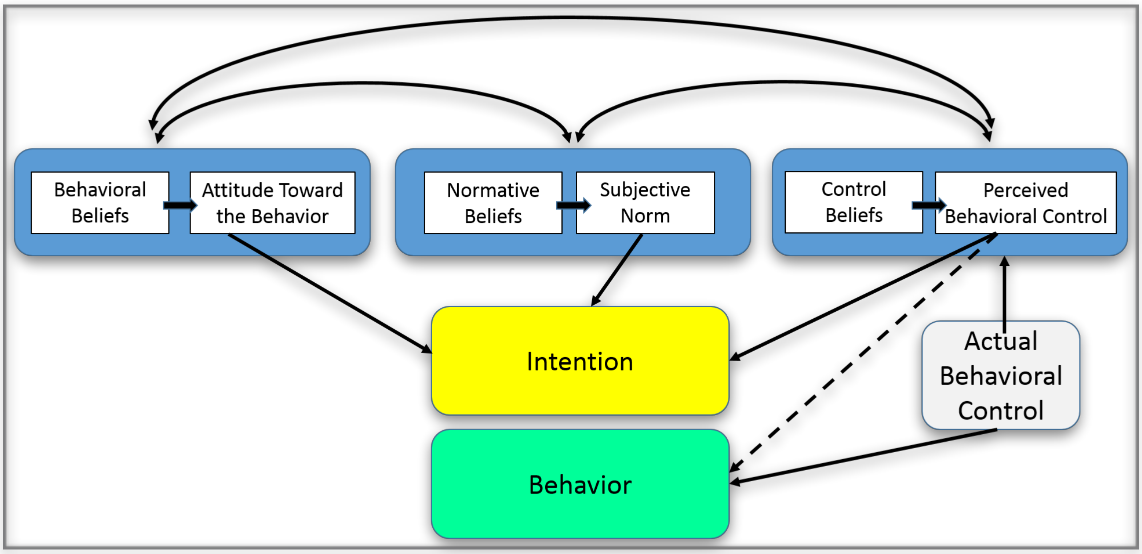

Figure 1: Constructs of Theory of Planned Behaviour (Ajzen, 1991)

The concept of Theory of Planned Behaviour (TPB) was introduced in psychology by Ajzen (1991) to improve the predictive power of the Theory of Reasoned Action with the addition of perceived behavioural control. TPB links one's beliefs to Intention and behaviour as shown in Figure 1 above.

Attitude towards a behaviour is dependent on behavioural beliefs of an individual, which are a person's subjective probability about the outcome of engaging in a behaviour. These behavioural beliefs together form a favourable or unfavourable attitude towards behaviour in question directly proportionate to a person's subjective probability about a behaviour producing intended outcome.

Subjective norms refer to the social pressure on an individual to perform or not to perform a particular behaviour. These are formed as a result of a person's perception of the beliefs of his family members and friends and are known as normative beliefs. Subjective norms play a part in shaping a person's intention towards a particular behaviour.

Control beliefs are an individual's beliefs about factors that may hinder or facilitate a particular behaviour. All the control beliefs together form an individual's Perceived

Behavioural Control (PBC) over performing a particular behaviour. PBC means the extent to which a person feels he/she can engage in a behaviour.

The above mentioned three constructs "attitude toward the behaviour," "subjective norm," and "perceived behavioural control" together form a person's intention to perform a behaviour which is a precursor for the behaviour in question. Ajzen (1991) explains a person with a positive intention and with given sufficient perceived behavioural control over behaviour is likely to act and indulge the behaviour.

2.2 Fair Trade and TPB

With the rising popularity of fair trade, it is implicitly clear a significant chunk of consumers show a favourable attitude and intention towards buying fair trade bananas. Global Fairtrade sales have consistently grown to € 7.88 billion in 2016 benefitting 1.6 million farmers across the globe [2]. Fair Trade impacts lives of farmers not just monetarily with a fair payment for their produce, also by providing training and support to farmers in developing countries as indicated in the annual Fair Trade report released in 2017 [2]. Consumer Attitude and Subjective Norm towards sustainable practices and Fair Trade are not the focus of this research.

A significant factor in shaping a consumer's Perceived Behavioural Control is the ability to access traceability information which is the focus of this thesis. Availability of trustworthy traceability information plays a significant role in shaping Perceived Behavioural Control and actual control of a person over verifying Fair Trade certification leading to buying behaviour. With the availability of such means to verify information using a mobile app, consumers can exercise control over verification of their product characteristics. Sayogo et al. (2018), have demonstrated with conclusive evidence in their paper, the significant role played by ICTs technologies in positively influencing consumer behaviour by providing consumers with product-specific traceability information. The authors also believe consumers are increasingly demanding compliance information beyond a logo or seal. By providing a blockchain based system for verifying product compliance, consumers are provided with a Behavioral control for verifying product information. It makes sense for a Fair Trade consumer to rely on verifiable information for making a purchase, rather than not.

2.3 What is Blockchain?

The term blockchain is used to describe a data structure, and also occasionally to a network or system (Xu et al., 2017). The name blockchain arises from the fact that data is stored as transactions in a block, and these blocks are linked with each other cryptographically forming a chain of blocks, and hence the name Blockchain (Gupta, M., 2018). Unlike central systems, blockchain ledger is validated and stored on a peer-to-peer network (Xu, 2016), where every peer maintains an identical copy of the ledger leading to a distributed way of storing data. Xu (2016: 1), have also best-described blockchain technology as "*one that enables records to be shared by all network nodes, updated by miners, monitored by everyone, and owned and controlled by no one*", The blocks are timestamped and linked cryptographically in a blockchain where any attempt to temper data is easily detected. Blockchains offers transparency of records to its participants and are decentralised systems; therefore no single entity is in control of the system.

In a business context, Gupta's (2018) definition of Blockchain accepted at IBM, precisely describes Blockchain as "a shared, immutable ledger that facilitates the process of recording transactions and tracking assets in a business network". Some examples of typical participants in a business network include manufacturers, suppliers, partners and logistics. Figure 2 below shows an example of a blockchain ledger used for storing vehicle registration transactions. Readers can infer from the Figure 2; blocks are connected using the unique hash of the previous block all way to the very first block known as the genesis block. Every block contains a unique hash of itself and the previous block, which helps link all validated blocks and discard malicious blocks.

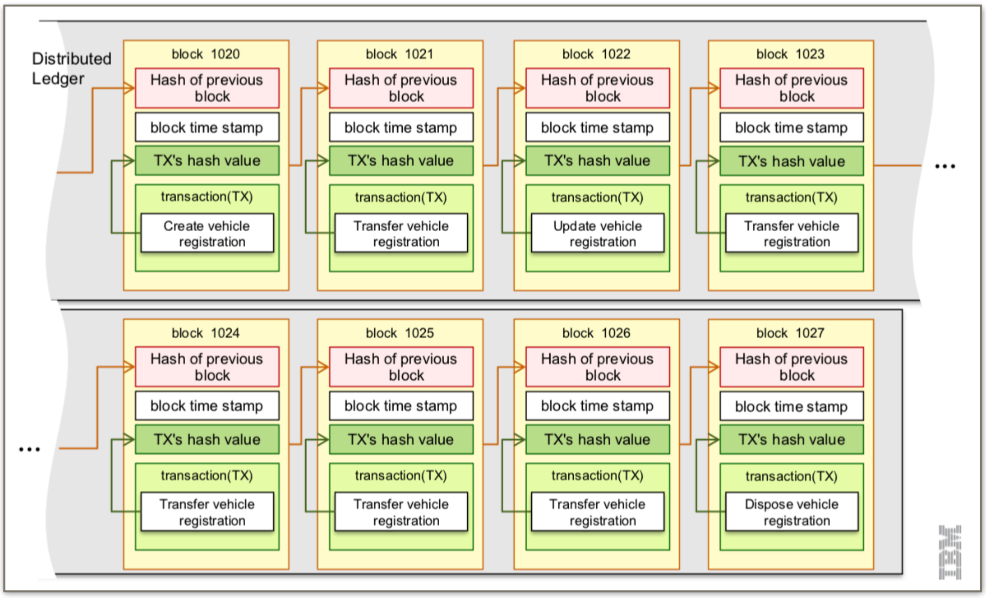

Figure 2: Transactions in linked Blocks. Source: IBM blockchain Platform.

A typical block inside a blockchain ledger has the following elements:

1. **Block hash:** a unique fixed length alphanumeric string that can be used to identify a block independently.
2. **Previous block hash:** The hash of the previous block which allows every block to be linked with the entire chain.
3. **Timestamp:** The timestamp of when a block is added on a blockchain.

4. **Transactions:** A transaction is an action triggered by the participant (Miraz & Ali, 2018), and one or more time-stamped transactions are a part of a single block in a blockchain.

Blockchains can also be characterised as permissionless (or public) when no restrictions apply in regards to who can join the network. Permissioned blockchains on the other hand, only allow known and invited participants to access the blockchain network. Permissioned blockchains are also known to offer higher scalability required for industrial applications.

2.4 Decentralisation & Trust in Blockchain

Traditionally transactions are carried out with the help of a mediator such as a bank, who is responsible for correctly transferring funds between the parties and updating balances (Xu, 2016) (Xu et al., 2017). Blockchain typically removes the reliance on third parties as the system is trusted to work fairly for all participants. In a decentralised blockchain system, participants do not need a third party to mediate transfers and also do not necessarily need to trust each other as well, as transactions are broadcasted to the entire network making it impossible to deceive anyone (Xu, 2016) (Xu et al., 2017). The transactions do not need approval from one single entity but rely on a set of specified rules. Hence, blockchain offers a trust-free environment for two parties to transact and removes the need of a trusted mediator. A central authority is also a single point of attack in centralised systems as databases can be updated by anyone maliciously (Xu et al., 2017), and a single point of attack on a centralised data source can sabotage all records of vital information. As every peer in a blockchain network maintains an identical copy of the ledger, there is no threat of a single point of attack and information is highly available. Transactions are validated by peers using the same protocol, and once consensus is achieved regarding the validity of transactions and order of transactions, transactions are added to the chain and are available for verification. Due to the validation required in consensus phase, blockchains cannot match the latency of centralised databases. Blockchain systems are decentralised or partially decentralised as data is stored on multiple peers rather than on a single server under the control of one authority.

2.6 Supply Chain Traceability

Traceability is an essential aspect in food and consumer industries as described by Olsen et al., (2013), and the authors have also given us a definition of traceability by combining four sources as they believe there is no standard definition of traceability. The authors looked at various definitions from ISO, a definition from Codex Alimentarius and the EU GFL regulations to arrive the following optimal definition of supply chain traceability. The final definition in the words of authors Olsen et al., (2013, p148) is: "The ability to access any or all information relating to that which is under consideration, throughout its entire life cycle, by means of recorded identifications." The definition indicates the information required to achieve traceability of a particular product, which is all information related to its entire life cycle. Another critical element in the definition is the requirement for recording all properties of product systematically, to achieve supply chain traceability of any product in question.

Aung & Chang (2014: 173) believe the following definition by Bosona & Gebresenbet (2013) is to be most informative which adequately describes characteristics of traceability in food chains, "*Food traceability is defined as a part of logistics management that capture, store, and transmit adequate information about a food, feed, food-producing animal or substance at all stages in the food supply chain so that the product can be checked for safety and quality control*". It is clear from the definition, safety and quality control are of prime importance in our food chains, which is achieved with traceability of product in all stages of a supply chain. Traceability systems effectively stores, captures and emits information regarding a product and its movement.

2.7 Objective of Traceability systems

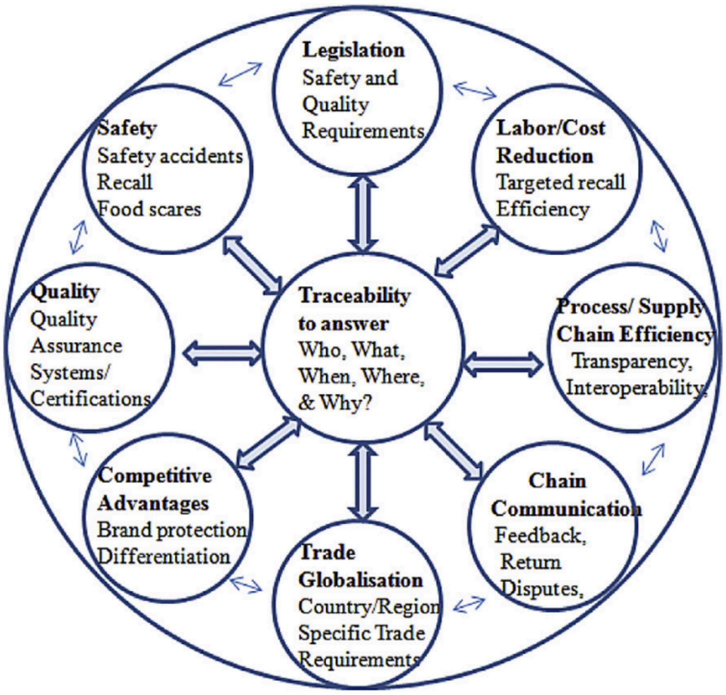

Figure 3: Drivers of traceability system's adoption (Aung and Chang, 2014).

The following objectives of traceability have been described using the extensive research of Aung and Chang (2014). First and foremost, traceability systems are the means to identify critical food safety issues and make adequate food recalls which would avoid harm to customers' health. These systems are traditionally employed based on centralised technologies to reduce the impact of food recalls by identifying supply chain problems quickly. Traceability systems provide means of gaining a competitive advantage and are also seen as a tool to improve the quality of raw materials. Quality is another motivating factor for food sellers, where traceability allows organisations to differentiate themselves based on product traits. From a consumer point of view traceability systems help gain consumer trust in the food chain and provides peace of mind regarding the safety of food. For producers, traceability systems also provide a means to continuously improve and minimise the impact of food hazards in a cost-effective way. Other drivers of traceability systems are present in Figure 3 below. As explained by Aung and Chang (2014: 174), "These drivers enforce traceability as a tool to answer the questions of "who (i.e., actor/ product), what (i.e., actor/product's information), when (i.e., time), where (i.e., location) and why (i.e. cause/reasons)" with regard to food safety, quality and visibility". In a more recent study, Spence et al. (2018), have recognised the aim of traceability systems in the meat industry to improve SCM particularly about controlling food risk and provide verifiable product information regarding quality attributes such as organic and fair trade production.

2.8 Characteristics of Traceability

Food Standards Agency (FSA, 2002) have prescribed three primary characteristics of traceability systems (Aung & Chang, 2014):

1. Traceability systems allow identification of unit/batches of all raw materials and products in the supply chain.
2. Traceability system should provide information regarding when and where units are moved and transformed.
3. Traceability systems to link data from various movements in supply chains.

Furthermore, traceability is also characterised as per the activity or the direction in which information is requested. Depending on activity there are three different types of traceability which are distinguished as follows (Aung & Chang, 2014):

1. **Back traceability or suppliers' traceability**: also known as tracing, is the ability to find the origin of products and characteristics at every point in supply chains.
2. **Internal traceability or process traceability**: The ability to trace products internally to organisations and while products are processed.
3. **Forward traceability or client traceability**: In contrast to backward traceability, forward traceability is the ability of a system to locate a product in any given time based on set criteria.

Traceability can also be characterised just as internal and external traceability, where internal traceability tracks part of the production process and external tracks the product throughout rest of the supply chains.

Chapter 3. Methodology

This chapter defines the overall research design used in this thesis. The purpose of this research is exploratory in the area of blockchain's use for supply chain management. As explained by Saunders et al. (2011), exploratory studies are used to gain insight into a topic, problem or a phenomenon and are likely to answer to questions originating with 'What' and 'how'. The exploratory research undertaken in this paper seeks to explore the blockchain phenomenon in supply chains to get an answer regarding 'what' and 'how' the technology can be put into practice that is beneficial for businesses and consumers. The reason for choosing exploratory research can be attributed to the author's lack of expertise in blockchain as well as supply chains.

The methodology used for this research is multi-method qualitative research consisting of interviews and a prior literature review. The research is linked with Interpretivism research philosophy. Interpretivists study meaning from a subjective perspective and the same goes true for this research as interview participants present their perspective on the use of blockchain technology from their own experience with it. In line with the purpose, this qualitative research uses induction for theory building where data is collected to build a richer theoretical perspective on blockchain's use in tracking products and making supply chains transparent. Primary data collection is done by interviewing experts and consultants from the Netherlands, who have practical experience with undertaking blockchain projects. Following a content analysis approach, the primary data is coded first to identify themes for further analysis and developing a richer understanding of the topic.

3.1 Literature review

A literature review is an essential part of a research project as it offers context and theoretical foundation for the research (Saunders et al., 2009). With a critical literature review conducted at the beginning of the research, the researcher can connect his work with what has been done in this field already. Furthermore, this literature review helps the researcher to demonstrate his understanding of key concepts, ideas and problems pertinent to the use of blockchain technologies in supply chains. Before beginning pursuit of published literature, Saunders et al. (2009), have also advised looking for existing systematic reviews on the topic. By doing so, a couple of papers systematically reviewing the technology until 2016 were found and used.

Apart for gaining theoretical knowledge, the objective for literature review is to find out what published literature say about the use of blockchain technology in achieving traceability across supply chains to present the option of researchers. Also, to find evidence in the literature for the use of blockchain in SCM, detecting fake and noncompliant consumer products. The literature review also aims to discover problems faced by supply chains currently that may be addressed with the use of blockchain technology.

The first step before searching for papers is to set the criteria and keywords for the search. The literature search is divided into two parts. The first part of the search is limited to blockchain technology, and it's fundamental concepts and applications. This is required to lay the theoretical foundation of blockchain in this project and gain an in-depth understanding of the technology and existing research in the area. The first search on blockchain resulted on over 10,000 hits on google scholar. Moving on, in the next part, the focus of search terms is shifted on supply chain traceability and the use of blockchain in supply chain management, along with the search for evidence indicating demand for traceability in supply chains which resulted in over 300 hits on google scholar. Table 1 show primary keywords used in the search on the left, and the additional keywords used to narrow down the search. The scope of the search is global and not limited to any one geographic location.

Search	Primary keywords	Additional keywords used	Hits	Papers included
1	- Blockchain OR "Blockchain technology"	- fundamentals - applications OR "use cases"	over 10,000	14
2	- Blockchain AND (SCM OR "Supply chain management ") AND traceability) - Supply Chain traceability	- traceability - transparency - detect AND (counterfeit OR fraud) - problems OR Challenges OR barrier	Approx 300	20

Table 1: Keywords used by Author for finding literature

The primary source of papers in this research is google scholar and Leiden University library catalogue. The reason for using google scholar is that it aggregates paper from various sources and Leiden University's catalogue can be linked with google scholar to find papers in one place from an additional source. The search was also conducted using university internet connection as it provides free access to a large number of papers, in April 2018 and September 2018. Additional keywords are used to narrow down the search to reduce the number of hits. It is also worth mentioning after the first couples of pages of results, the relevance of articles to the topic significantly reduced. From the available hits, the researcher read the abstract and additional text to understand the nature and exact topic of the study after which relevant papers were downloaded and added to Mendeley software for organising and removing duplicates.

Desk research was also conducted besides literature review which resulted in the discovery of papers from the industry. These papers are written by industry players IBM, TNO and Deloitte, were also included to analyse their opinion on the use of technology. These companies have successfully created proofs-of-concept in supply chains for their clients. Other research in the form of white paper from Fairfood is also taken into account later in the research due to the success of Fairfood's pilot programs in achieving traceability with coconut and coffee beans. The desk research also helped the author in understanding the use of blockchain solutions such as Hyperleder Fabric and the secondary data discovered here is used to support the primary data collected in interviews.

3.2 Interviews protocol

The objective of Interviews in this research is to collect primary data in order to answer the research questions. In line with the exploratory purpose of this research, the interviews are semi-structured. This gives the researcher an opportunity to discuss pre-defined themes and questions to get an opinion of the interviewee with the possibility of open discussion. The flexibility of semi-structured interviews allows omitting themes based on the organisational context and expertise of the interviewee (Saunders et al., 2011). The four themes identified for discussion with experts, based on the research questions, are as follows:

1. Use of blockchain in consumer supply chains.
2. Advantages of using blockchain technology in supply chain management
3. Barriers to entry and challenges for blockchain adoption in supply chain management.
4. Implementation for traceability of consumer products.

To find professionals with expertise in the field of the blockchain, LinkedIn is used as the primary source. Expert's profile showing experience over two years in the use of blockchain technology were particularly targeted on LinkedIn for their valuable opinion. Contact was made with more than 25 people for interviews based on the information found on their LinkedIn profile. People who responded were then further informed about the research objectives, and a date for the interview or telephonic consultation is set as per their availability and preference. Identities of experts are kept anonymous for confidentiality reasons and only disclosed to the supervisors of this research thesis. Experts are denoted as E1, E2, E3 & E4 in this paper, and an example of an initial message sent Zhijie Ren on LinkedIn is shown in Appendix 1. A comparative summary of data collected from interviewees is presented in Appendix 2.

3.3 Collecting qualitative data

The primary data needed for this research is obtained via interviewing blockchain experts. In cases, where the researcher was able to record the respondents, the conversation was recorded and transcribed thereafter. In other cases, where the recording was not possible, notes were taken during the telephonic conversation. Questions based on the previously mentioned themes are presented in Table 2 below, are these are used to collect data during interviews.

Theme	Questions
1. Introducing Research	As you may already know supply chain traceability is one of the use cases of blockchain technology. For my research thesis, I wish to explore the use of a permissioned blockchain in achieving product traceability. I am interested in finding out possible ways to implement traceability where consumers can see provenance and compliance of their products. Along with that, I am interesting in highlighting benefits and barriers for businesses interesting in making use of technology in supply chains. That's a brief overview of my research, could you please give me an overview of your experience with blockchain so far ?
2. Blockchain in SCM	- Is the use of blockchain technology for SCM effective in practice? - Is blockchain effective in tracking products all along the supply chain? - Is blockchain cost effective in practice?
3. Advantages	- What are the advantages/benefits of using blockchain for SCM in practice? - Is it possible to solve the problems of child labour ? - Is it possible to human rights violations with blockchain technology? - Is it possible to solve the global problems of drug counterfeiting with blockchain?
4. Barriers to entry	- What are the barriers to entry in using blockchain for SCM in your opinion? - Are there are any legal implications of using blockchain technology in SCM?
5. Implemention	- What kind of blockchain implementations and consensus algorithms are suited for SCM? - Is ethereum cost effective for implementing in supply chains? - What are your thoughts on the use of permissioned blockchains such as Hyperledger?

Table 2: Questions based on themes for collecting data. Created by Author.

3.4 Analysing qualitative data

The research method used to analyse data is qualitative content analysis. Hsieh and Shannon (2005: 1278) have described qualitative content analysis as a "*research method for the subjective interpretation of the content of text data through the systematic classification process of coding and identifying themes or patterns.*" This method is well known for extracting meaning out of qualitative data.

The first step in analysing data is to become familiar with the data obtained during interviews. This is done by thoroughly reading the transcripts and notes, and also writing a small summary of the raw data. By thoroughly reading and re-reading the transcripts and summary, data becomes more familiar, and the researcher can find meaning, themes and recurring patterns in the data. Next, to categorise data available in transcripts and notes coding is used, and codes in the form of single words or phrases are added to extracts of data. The code provides meaning for a single extract of data, and this makes data more accessible for analysis. The source of these codes is data-driven and codes e are derived by the researcher based on the data present in the transcriptions. In this research, codes are added to paragraphs as a unit of data that is summarised by the code(s). Themes are developed by observing the codes and patterns originating from data. The results are discussed in the conclusion section to answer the research questions. Important themes identified from primary data are addressed in the discussion chapter 8.

3.5 Answering the research questions

The following Table 3, provides an overview to the readers on how the research questions have been answered in this research. The source of the questions is marked with X on the right column as per the relevance.

Questions	Interviews	Secondary
Overarching question: How can we achieve end-to-end traceability and transparency in banana supply chains along with creating verifiable certifications of Fair Trade and organic bananas with the use of permissioned blockchain technology?	X	
RQ1: Is blockchain effective in tracking products all along the supply chain?	X	
RQ2: What are the advantages of using blockchain technology in supply chains?	X	X
RQ3: What are the advantages of using permissioned blockchain technology in supply chains?	X	X
RQ4: How can blockchain technology be implemented in supply chains?	X	X
RQ5: What are the incentives for stakeholders to use blockchain technology for supply chain management?	X	X
RQ6: What are the barriers and challenges in adopting blockchain technology for supply chain management?	X	

Table 3: Sources of answers to Research Questions

Chapter 4: Blockchain

It is already clear that the term "Blockchain" is associated with data structure where the information resides inside transactions, which are further part of linked blocks and stored on every participating peer. Blockchain systems are managed by a peer-to-peer network and peers follow a set protocol for achieving consensus regarding validity of transactions. Applications use immutable data stored on the blockchain ledger to provide functionality to its end users. This chapter provides a critical review of the literature on blockchain technology by first introducing characteristics of blockchain systems and then moving on the role of consensus, cryptography techniques used in blockchain systems, various types of blockchains, after which applications and use cases are outlined with the support of published works.

4.1 list of studies included (N=14)

The following Table 4 gives the reader an overview of the literature and sources use on the use of blockchain technology. The papers are ordered in ascending order of the year of publication.

Author (s)	Topic & year of study	Type and scope	Purpose and/or findings
Nakamoto, S.	Bitcoin: A peer-to-peer electronic cash system. 2008	Theoretical system for digital cash transfer in the form of bitcoin.	This paper describes the very first decentralised use case for transferring a digital asset (bitcoin in this case). By solving the problem of double spending with the help of peer-to-peer network, Nakamoto (2008) proposes a permissionless solution to remove the reliance on banks. Users on the Bitcoin network can transact with each other without a mediator. POW is used to achieve consensus among nodes.
Yli-Huumo, J., Ko, D., Choi, S., Park, S., & Smolander, K.	Where Is Current Research on Blockchain Technology?—A Systematic Review 2016	Systematic review to identify the current research on blockchain technology from the literature.	The authors conducted a systematic mapping study with the objective to understand the current research topics, challenges and future directions regarding Blockchain technology from the technical perspective. Results indicate that in 2016, most of the research has been focused on improving the limitations of bitcoin concerning security and privacy. Also, 80% of the papers were focused on bitcoin, with rest of the 20% focusing on other blockchain applications such as smart contracts and licensing.
Zheng, Z., Xie, S., Dai, H. N., & Wang, H.	Blockchain challenges and opportunities: A survey. *2016.*	Comprehensive survey on blockchain technology from both technological and application perspectives.	The authors present an overview of various blockchain technologies outlining architecture, characteristics, consensus approach, applications and challenges. Blockchain can be applied to variety to fields beyond bitcoin: Finance, IOT, Public and social services, reputation systems and for security & Privacy. **Key characteristics**: decentralisation, persistency, anonymity and auditability. **Challenges**: Scalability, privacy leakage and selfish mining.

Author (s)	Topic & year of study	Type and scope	Purpose and/or findings
Xu, X., Weber, I., Staples, M., Zhu, L., Bosch, J., Bass, L., ... & Rimba, P	A taxonomy of blockchain-based systems for architecture design. 2017	Worldwide. Qualitative study using literature, government and technical report data along with analysing documentations of industrial products.	The paper aims to classify various blockchain designs which would help identify and evaluate design decisions for architecting a solution. A taxonomy of blockchains and blockchain based systems is presented to help with designing performance and quality attributes of blockchains systems. The paper also describes five fundamental properties of blockchain systems as immutability, non-repudiation, integrity, transparency, and equal rights. Additionally, the authors present data privacy and scalability as two non-functional properties of blockchains. The design process starts from the decision to decentralise a trusted third party.
Wüst, K., & Gervais, A.	Do you need a Blockchain? 2017	Qualitative study. SCM, interbank payment and DAO (Decentralised autonomous organisations.)	Provides a structured methodology for evaluating use cases in Supply Chain Management, Interbank and International Payments, and Decentralised Autonomous Organisations. Describes key differences between public and permissioned blockchains as opposed to centralised systems. Outlines most relevant properties of blockchains as *Public verifiability, transparency, privacy, integrity, redundancy and trust anchor.* The paper also helps in choosing between permissionless, permissionless or centralised systems based on the information provided by the authors. There are valid uses for these three types of systems. Two critical technical considerations for blockchain systems are **throughput** and **latency** as outlined in the paper.
Miraz, M. H., & Ali, M.	Applications of Blockchain Technology beyond Cryptocurrenc y 2018	Qualitative study for applications of blockchain beyond bitcoin in non-monetary systems.	Summarises existing literature to point out non-monetary related use cases of blockchain: storing and verifying legal documents including deeds and various certificates, healthcare data, IoT, Cloud and so forth. The authors also present Gartner hype cycle which classifies blockchain to reach maturity in 2 to 5 years.
Xu, J. J.	Are blockchains immune to all malicious attacks? 2016	Qualitative study to identify risks in blockchain networks from the literature.	The author presents attacks on information systems that can be prevented with the use of blockchain, along with malicious attacks which make blockchains vulnerable. As per the results, blockchain is vulnerable to 51% attacks, identity thefts, illegal activities and system hacking.
Zhao, J. L., Fan, S., & Yan, J.	Overview of business innovations and research opportunities in blockchain. 2016	Qualitative study to present the overview blockchain research and development.	The paper present research opportunities in exploring and validating business opportunists with use the blockchain. Currently (2016), most of the research is conceptual and in a prescriptive level that outlines business applications of blockchains. There is a lack of descriptive research on blockchains use. The authors believe blockchain research is expected to address the issues of trust, sharing, and privacy as part of human society.

Author (s)	Topic & year of study	Type and scope	Purpose and/or findings
Glaser, F.	Pervasive decentralisation of digital infrastructures: a framework for blockchain enabled system and use case analysis. 2017	Theoretical Ontology of blockchain systems.	The author shows how blockchain technology could be incorporated into the existing landscape of digital services, processes and infrastructures by presenting an ontology that describes common terminology, core concepts and components, their relationships as well as innovative features of blockchain technology. The architecture of Blockchain systems is divided into two layers: 1. Decentralised Fabric layer which is also known as the infrastructure layers which holder the ledger and permissions. 2. Application layer which responsible for the services needed by decentralised applications.
van Deventer, M. O., Brewster, C., & Everts, M.	Governance and business models of blockchain technologies and networks. 2017	Case study of various governance and business models in existing blockchains implementations.	An organisation planning to deploy blockchain technologies is faced with a make or buy decision and authors advice to choose carefully based on the business model, and governance of source code in the chosen approach. "**Make**: develop and deploy a new blockchain network." "**Buy**: join an existing blockchain network that is run by others." The authors at TNO describe the two above mentioned decisions from governance, and business models point of view and believe that an organisation should only join a blockchain network if its governance and business models are acceptable.
Androulaki, E., Barger, A., Bortnikov, V., Cachin, C., Christidis, K., De Caro, A., ... & Muralidharan, S.	Hyperledger fabric: a distributed operating system for permissioned blockchains 2018	Implementation of Hyperledger Fabric for POC.	An overview of a modular and open-source Hyperledger fabric used for implementing permissioned blockchains. The paper describes Fabric's architecture, design decisions, security model, implementation aspects and distributed application programming model. **Results**: The authors demonstrate that Fabric permissioned blockchain achieves throughput of 3500 transactions per second with sub-second latency.
Udokwu, C., Kormiltsyn, A., Thangalimodzi, K., & Norta, A.	An Exploration of Blockchain enabled Smart-Contracts Application in the Enterprise. 2018	Systematic literature review on Smart contracts.	The authors explored use cases of smart contracts on enterprises. Three top domains for smart contract use cases are healthcare, SCM, and finance. Transparency and trust are the primary reasons for organisations to use smart contracts. Other reasons include data security/privacy, resource management, tamper-proof, and interoperability. **Limitations**: usability and complexity issues, standardisation, lack of testing and practical experience, and design architecture issues.

Author (s)	Topic & year of study	Type and scope	Purpose and/or findings
Gratzke, P., Schatsky, D., & Piscini, E.	Banding Together for Blockchain. 2017	A paper by Deloite, analysing existing blockchain consortiums and the benefits they bring to stakeholders.	Authors explain two types of blockchain consortiums as Technology-focused and Business-focused and believe that consortia will play an important in the commercialisation of the technology. The authors show the emergence of consortiums in blockchain by highlighting 40 blockchain consortiums that were active at the time of the paper, and also insist that in order to use the technology effectively, enterprises need to be a part of a consortium. Benefits of forming and joining a consortium include: 1. low-risk effort to stay on current trends of blockchain technology. 2. Learn about what competitors are doing. 3. Defend against potential new threats. 4. prepare to implement the technology.
Cachin, C., & Vukolić, M.	Blockchains consensus protocols in the wild. 2017	A review of various consensus used in blockchain technology focusing on permissioned networks.	The authors summarise the consensus protocols used in the following consortium blockchain implementation in practice: Hyperledger Fabric; Tendermint; Symbiont Assembly; R3 Corda; Iroha; Kadena; Chain; Quorum; and MultiChain. The consensus approach used in Hyperledger Fabric offers: better scalability. Separation of trust assumptions for transaction validation and ordering. Support for non-deterministic smart contracts. Partitioning of smart-contract code and data across nodes. Offers modular consensus implementations.

Table 4: List of studies included on Blockchain.

4.2 Characteristics of Blockchains

This section looks at the inherent characteristics of blockchain systems. Zheng et al. (2016) have described the key characteristic of blockchain technology as decentralisation, persistency, anonymity and auditability. Wüst et al. (2017) on the other hand believe the key properties of blockchains to be public verifiability, transparency, integrity, redundancy and trust anchor. Interestingly, in the opinion of Xu et al. (2017), fundamental properties of blockchains include immutability, non-repudiation, integrity, transparency, equal rights and trust. These are explained next collectively from the opinion of the authors mentioned above.

1. **Decentralisation**: In conventional systems, a third party such as a bank is used to validate transactions, which also results in cost and performance bottlenecks. A key aspect of blockchain systems is decentralisation, which means that participants on a blockchain network can start and verify transactions with relying on a mediator. Transactions are conducted P2P (peer to peer), and without authentication from a centralised authority. Zheng et al. (2016) believe this reduces the server cost and the performance bottlenecks at central servers.

2. **Persistency & Immutability**: Transactions in a blockchain network are confirmed and stored on every participating peer on the network. It is nearly impossible to tamper the transactions once transactions are confirmed, and any such falsification attempts can be easily detected. The transactions will reside on the ledger until the network is up and running.
3. **Anonymity**: Users of a blockchain network use private and public keys to transact, and every user is identified with a unique address. There are no restrictions on the number of addresses a user can have, and this also means that no central authority keeps any information of the user which helps preserve some privacy and keeps the user anonymous on the network.
4. **Auditability**: Data on a blockchain network can be traced back to its origin. Validated transactions are recorded with an accurate timestamp and linked together which allows users to see the previous records as well.
5. **Public verifiability**: Anyone on a blockchain network can check the state of a system at any given time. Anyone can also verify that state of the system was changed as per the protocol and the state is identical for every peer. In the case of centralised systems, the state can be different for every user and banks are used to confirm the state.
6. **Transparency**: The information of blockchain and the process of updating state is transparent and observable by anyone.
7. **Integrity**: The data stored on a blockchain is resistant to unauthorised modifications, and we can be sure that retrieved data is always correct. In other words, data stored on a blockchain is trustworthy. In centralised systems, integrity is lost when the system is compromised.
8. **Redundancy**: In blockchain systems, redundancy is offered through replication of ledger with certain transactions on every peer. The availability of information is high in blockchain systems as every peer keep the same copy of ledger. In a central system, it is done by adding servers and creating backups.
9. **Non-repudiation**: The historical chain of transactions stored immutability along with cryptographic signatures offers non-repudiation. With the help of cryptographic proof, a party cannot deny sending transaction and can be easily authenticated.
10. **Equal rights** allow participants to have the same function, unlike central systems where some users get additional privileges. A key point to note here is that even though every user has equal rights, access to some information can be restricted in permissioned implementations of the blockchain.

11. **Trust**: The participants in a blockchain network trust the network itself and the protocol it follows. The protocol behaves in the same way for every participant and can be trusted to perform impartially.

4.3 Smart Contracts

A smart contract refers to a self-executing piece of code or program that is stored on a blockchain, and it would perform a transaction once conditions mentioned in the contract are fulfilled. Grech et al. (2017) have described smart contracts as a computerised transaction protocol that executes the terms of a contract, and the author also points out the concept has been around for a while but now can be implemented with the use of blockchains. Once a smart contract is agreed and deployed, it would execute automatically in the future and requires no further intervention from the participants bound in the contract. Smart contracts provide transparency and are trusted by both parties, which are the main reasons for organisations to use smart contract in blockchain implementations as noted by Udokwu et al. (2018), who also found main areas of smart contract applications to include healthcare, SCM, and finance.

4.4 permissionless vs permissioned blockchains

Permissionless Blockchain: In permissionless blockchains, also known as public blockchains, anyone can access the network to verify or send transactions (Wüst et al., 2017). In addition to that, anyone can validate transactions by participating in the consensus mechanism. There are no restrictions on who can join the network, and the network is open to all. The ledger is publicly visible to anyone along with the transactions contained in each block. Such a blockchain typically uses consensus algorithms like proof of work or proof of stake to achieve consensus among peers regarding the validity of transactions. Bitcoin and Ethereum are examples of permissionless blockchains where anyone can join the network to send/verify transactions, and also join the mining process to write transactions on the blockchain. Mining in bitcoin uses proof of work algorithm to publish transactions; where miners are rewarded with a fee in return by the network for the computing power committed by the miner. Miner's reward comes from the fee collected from every transaction which is paid by the end user per transaction.

Permissioned Blockchain: In a permissioned blockchain implementation, access is limited to authorised and invited participants only (Wüst et al., 2017). Since the identities of participants are known in advance, there is no need for proof of work like consensus mechanism in the permissioned blockchain, which also provides more scalability regarding latency and throughput. The identities of participants are created in the form of digital certificates issued by Certificate Authority (CA) and secured by a private key. Since the identities and roles of participants are well known, access can be better managed and granted as per the role of the participant in a business network. Figure 4 below highlights key differences between the two types of blockchain solutions discussed in this section against a central database which is the primarily used technology today for storing transactional information.

	Permissionless Blockchain	Permissioned Blockchain	Central Database
Throughput	Low	High	Very High
Latency	Slow	Medium	Fast
Number of readers	High	High	High
Number of writers	High	Low	High
Number of untrusted writers	High	Low	0
Consensus mechanism	Mainly PoW, some PoS	BFT protocols (e.g. PBFT [6])	None
Centrally managed	No	Yes	Yes

Figure 4: Comparison of Blockchain types (Wüst et al., 2017).

4.5 Consensus in blockchains

A consensus mechanism is an agreed upon method for adding new blocks to a blockchain ledger. In a blockchain systems there is no central node that provides replication of ledger on other nodes, and nodes may or may not trust each other, therefore it is necessary to enforce some protocols to make sure ledger is consistent on every node. (Zheng et al., 2016). Every transaction in a blockchain network is verified by the consensus from majority of the participants in the network, therefore fraudulent transactions unable to pass collective verification done by nodes (Leon Zhao et al., 2017). A popular consensus approach used in Bitcoin blockchain is called Proof of Work which is described next, along with POS and BFT.

4.5.1 Proof of work (PoW)

Zheng et al., (2016) have explained PoW protocol in detail which is typically used for achieving consensus in permissionless blockchains such as Bitcoin and Ethereum. Each node in the system making use of PoW is calculating a hash value for a continually changing block header, and the hash value has to be equal to or smaller than a proposed value. All participants simultaneously calculate the hash, and after a node finds the resulting value, all other nodes must validate by looking at proof of work provided by the solver node. After which transactions are checked and validated in the form of a block which is added to the blockchain permanently. Nodes that calculate the value of hash as referred to miners; and miners rewarded in a small portion of bitcoin in return for applying computation power. When miners are simultaneously working to solve the hash, it is also possible for two miners to generate the next block which results in two branches of chain, however it is unlikely that the two branches will the generate the next block at the same time, and the longest chain is considered the authentic one discarding the other branch. Miraz & Ali (2018) believe this mathematical challenge ensures the security of the blockchain by maintaining a digital ledger that is considered unalterable. Zheng et al. (2016) agree that miners have to do many computing calculations in PoW, and these calculations waste computational resources. Gupta (2018) has deemed PoW as an unnecessary expense for business blockchains as identities of participants are always known, and the extreme amounts of calculations can be avoided in this situation. Leon Zhao et al. (2017) have also expressed concerns over this strict verification process which has a very high latency and limits the scalability of blockchains using PoW.

4.5.2 Proof of Stake (PoS)

PoS is an energy-saving alternative to POW. As put by Zheng et al. (2016), in order to mine transactions users are required to prove ownership of currency used in blockchain, as it is believed currency holders are unlikely to attack the network as they don't. Selection of miner based on currency would mean that richest will get the advantage, however some PoS implementation mitigates this by making a random selection which seems more fair. Compared with PoW, PoS saves more energy and is more effective in terms of scalability as it can provide better throughput and lower latency.

4.5.3 Delegated proof of Stake (DPOS)

Similar to POS, miners get to generate blocks according to their stake, however, in DPOS stakeholders elect their delegates to generate and validate a block (Zheng et al., 2016). Such a system typically contains fewer nodes than PoW and blocks can be confirmed quickly in DPOS. The block size and block intervals can be adjusted appropriately. An advantage of over POS is that dishonest delegates can be voted out of the network easily by stakeholders.

4.5.4 Practical Byzantine fault tolerance (PBFT)

PBFT is a popular consensus approach for permissioned blockchain network as it requires identities of participants to be known in advance. As explained by Zheng et al. (2016), PBFT (Practical Byzantine Fault Tolerance) is a replication algorithm to tolerate Byzantine faults and can handle up to 1/3 malicious byzantine replicas. With PBFT, a new block is proposed every round by selecting a primary node based on some rules and the primary is responsible for ordering the transaction. The ordering process is dived into three parts namely pre-prepared, prepared and commit. In each of these phases, a node will only enter the next phase if it receives votes from 2/3rd of all nodes, which is why PBFT can handle up to 1/3rd malicious nodes.

4.6 Cryptographic techniques used in Blockchain

Blockchain provides us with an immutable digital ledger and uses an inbuilt trust mechanism with the use of the cryptographic techniques (Huckle et al., 2017). These techniques are explained next and provide an understanding of trust that depends on cryptography.

1. **Cryptographic hash functions** are used to create a fixed length hash value irreversibly from any arbitrary data using mathematical algorithms that are impossible to invert. A hash function a one-way function that maps any data into hash instantly. The resulting hash created is always of fixed length, and deterministic, which means that the hash created will always be the same for a given data. Slight changes in the input would drastically change the output of the function, and no two inputs have the same hash value. This technique is useful in making sure that data is not altered during its transmission on the internet. Figure 5 below shows a model hash function where the input file in the form of any arbitrary data goes through a hash function to generate a fixed length corresponding hash value.

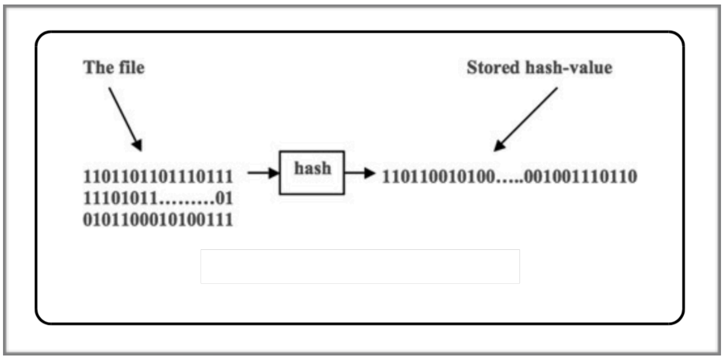

Figure 5: Hash function (Huckle et al. 2017).

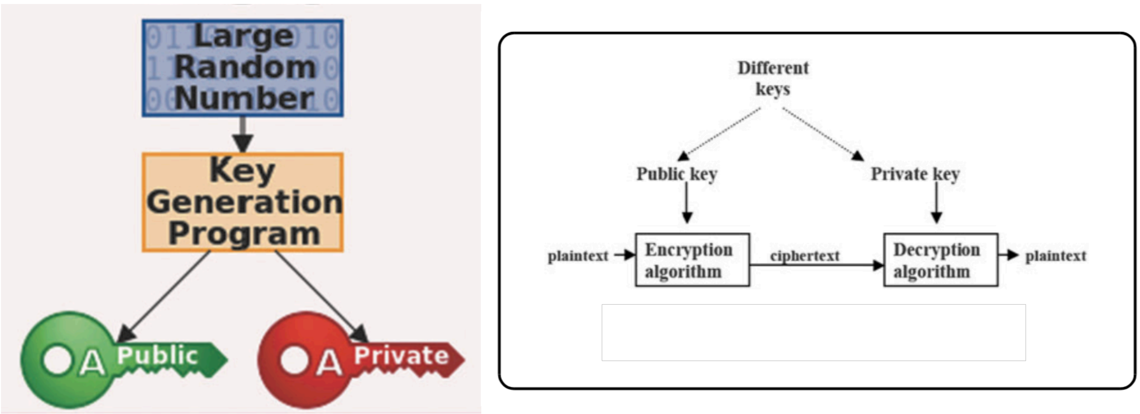

Figure 6: Public and private key encryption (Huckle et al. 2017).

2. **Public key cryptography (PKC)**: This technique is quite famous for encrypting and decrypting information sent over the internet. In a PKC system, an individual is issued with two asymmetric keys which are used to encrypt and decrypt data. Public keys are shared publicly with everyone who sends information while the private keys are not shared and used to decrypt the information that is received.

They two keys are created from a large random number as it can be seen in Figure 6, along with the process of encryption to create cypher text from plain text. The individual can only decrypt this cypher text in possession of the private key associated with the public key that is used to encrypt that information; which also means that the secrecy of private key is of crucial importance in such a system. Anyone who in possession of the private key can decrypt the information.

3. **Digital signatures** require public and private key to operate as well, where the public key is made available to the verifier of the signature. Digital signatures are a way to check the integrity of the received message. In other words, these signature lets us verify the sender is whom we expect and not an impersonator. Senders use their private key to attach a Digital signature with the message, and receivers can verify that signature is valid using the public key of the sender. The signature will only be valid if it signed by the private key of the sender.

4.7 Use cases of Blockchain Technology

Blockchain is able to facilitate transfer of digital assets such as Bitcoin without the use of a central authority, as participants can verify and initiate transfers themselves by relying on tamper-proof data along with various cryptographic techniques. Blockchain provided a mechanism to conduct peer-to-peer transactions with out the need for intermediary third party (Miraz & Ali, 2018). Figure 7 sums up the general process of how blockchain transactions taking place on a peer-to-peer work outlining the use case of transferring money without relying on a bank.

There overall process above is comprised of four steps which are described below from the work of Miraz & Ali (2018):

1. **Triggering transaction**: In the above example, Bob wants to transfer funds to Alice on a blockchain network. Once Bobs sends the request to transfer money, the initiated request is represented as a transaction on the network sent via an application interacting with the peer-to-peer network. The transaction is then broadcasted to all participants, in other words, to every peer on the network.
2. **Validation and verification**: Once the transaction is broadcasted, it is sent for approval and checked for validity by the peers. The network in this step rejects invalid transactions.
3. **Creating a new blockchain**:Once the transaction is valid and accepted by peers, it is fed into a block with the corresponding unique hash value of the block.
4. **Adding a block to the chain**: In the last step, blockchain is added to the chain and from there one the transaction is added to the ledgers is available for verification. Bob and Alice both can verify the transfer of funds without relying on a bank to mediate or verify transfer of assets.

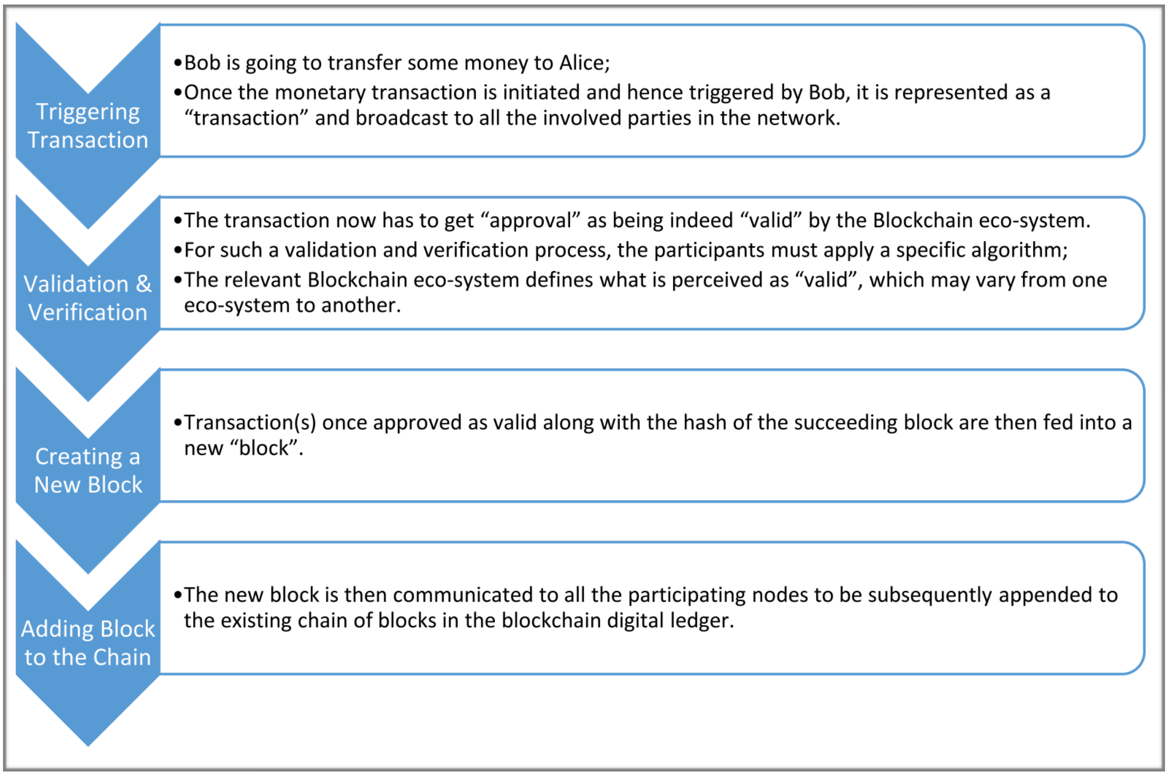

Figure 7: Overview of the transaction process in a Blockchain system (Miraz & Ali, 2018).

As further explained by Miraz & Ali (2018), the initial and primary concern of blockchain applications is to maintain and ensure trust in the system. Blockchain systems follow a mechanism trusted by its participants. Various researchers have also advocated the use of blockchain in areas beyond bitcoin and cryptocurrencies, where transactions can be modulated to store supply chain or healthcare data for example. It is also clear these use cases involve storing data on blockchain immutably to create a trust anchor.

Xu (2016) believes blockchain may also be applied in a wide range of other domains such as IoT (Internet of Things), real estate, supply chain management, insurance, and healthcare. Wüst et al. (2017) have identified distributed cloud storage, smart property, Internet of Things, supply chain management, healthcare, ownership and royalty distribution, and decentralised autonomous organisations among other use cases of blockchain technology in their paper. Miraz & Ali (2018) note applications of blockchain in enabling limitless applications such as storing and verifying legal documents including deeds and various certificates, healthcare data, IoT, Cloud and so forth.

4.8 Blockchains are vulnerable too

Even though blockchains offers a mechanism to detect fraudulent behaviour along with higher security than centralised information systems, it would naive to think blockchains are completely secure. Blockchains are prone to malicious attacks, and these attacks should be considered carefully before implementation (Xu et al., 2016). Even though blockchain eliminates many threats mainly associated to centralised technologies, it still, however, is prone to malicious attacks like 51% attack, account take-over, digital identity theft, money laundering, and hacking.

4.9 Conclusion

With the help of published literature, this chapter has provided its readers with an in-depth overview of blockchain technology outlining the fundamentals of the technology and types of blockchain along with cryptographic techniques in blockchain networks. In summary, Blockchain systems provide a trusted mechanism to conduct transactions without relying on a mediator such as a commercial bank. Cryptographic techniques such as digital signatures and public key cryptography provide an enhanced layer of security and trust in the system. The use of such techniques also allows blockchain systems to catch malicious behaviour and invalidate fraudulent transactions by providing provenance of information present in the systems. Blockchain's rise with Bitcoin and arrival of smart contracts have opened up new use cases and opportunities that could potentially revolutionise many industries as discovered during this critical review. Supply chain management is one area where blockchain can consistently validate and store transactions from participants in the entire network, providing consumers with a digital trail of their product's origin and journey. In the coming chapter, a critical review is presented on the use of blockchain for Supply Chain Management.

Chapter 5: Supply chain Management

Researchers have presented Supply chain Management as one of the areas where blockchain technology can potentially revolutionise many industries. After presenting a critical review on blockchain technology and its potential uses cases in the previous chapter, this chapter is focused on critically reviewing the literature on the use of blockchain for supply chain management and supply chain traceability. By doing so, relevance and impact of blockchain are put forward to the readers. Besides, the goal of this review is to present problems in supply chains, benefits and opportunities that arise from the use of use of technology in supply chains along with requirements for achieving traceability in the supply chains. Next, before diving into the review, a list of papers included in the critical review is presented with a summary of their results.

5.1 List of studies included (N=20)

The following Table 5 represents the literature included on SCM, traceability and the use of blockchain in supply chains. These papers are arranged by the year of study in ascending order.

Author (s)	Topic & year	Type	Purpose and/or Findings
Dickinson, D. L., & Von Bailey, D.	Experimental evidence on willingness to pay for red meat traceability in the United States, Canada, the United Kingdom, and Japan. 2005	Used Vikrey auctions to generate willing to pay for traceable red meat and related characteristics. 54 participants included from each UK and Japan. 108 included from each USA and Canada in the study.	Traceability systems are valued by end customers and should not be consider extra costs as customers are willing to pay for traceability and even more for other characteristics of food items that are verifiable via a traceability system. The results of the experiments show that in 2005, consumers are willing to pay a significant price premium for a traceable red meat, and even a higher price premium for other characteristics of red meat, namely meat safety and humane treatment of the animal.
Choe, Y. C., Park, J., Chung, M., & Moon, J.	Effect of the food traceability system for building trust: Price premium and buying behaviour. 2009	Survey of 491 consumers in Korea, to analyse buying behaviour and price premium with reduced uncertainty provided by a traceability system.	Based on the results from data collected in 2009, Korean consumers are willing to pay more for food managed with the traceability system, along with with willingness to purchase greater quantities of traceable food. The results also indicate it is important to provide truthful information about food safety and quality through the Food Traceability System, because trust between the seller and consumer has been found to be the most important mitigator of uncertainty.

Author (s)	Topic & year	Type	Purpose and/or Findings
Olsen, P., & Borit, M. (2013).	How to define traceability. 2013	Literature review to find, compare and contrast various definitions of traceability.	There authors have operationalised the concept of traceability using definitions from: 1. ISO 8402 2. ISO 9000 and ISO 22005 3. Codex 4. EU GFL 5. Moe (1988) "The ability to access any or all information relating to that which is under consideration, throughout its entire life cycle, by means of recorded identifications."
Aung, M. M., & Chang, Y. S.	Traceability in a food supply chain: Safety and quality perspectives. 2014	Literature review to operationalise food traceability	Aung and Chang point to the fact that current food labelling system cannot guarantee food is authentic, good quality and safe. This paper presents comprehensive information about traceability where traceability is applied as a tool to assist in the assurance of food safety and quality as well as to achieve consumer confidence. Food chains clearly require real-time traceability as it reduces the impact of contaminated food by making rapid recalls. Authors believe traceability should be extended to consumers who can verify product information using mobile phones to read product data. The paper also defines traceability, its objectives and requirements of traceability regrinds food safety and quality.
Egels-Zandén, N., & Hansson, N.	Supply chain transparency as a consumer or corporate tool: The case of Nudie Jeans Co. 2016	Customers on the website of Nudies jeans Co., were shown an option to view production guide, which showed sustainable and fair trade practices of the Swedish company.	The paper analysis consumer buying behaviour to determine whether transparency in supply chains can be a consumer tool which can be used to pressure companies into releasing supply chain & production information. Or, if its a corporate tool to increase sales. The authors conclude transparency can be a useful corporate tool to increase a consumer's willingness to buy. Results indicate 1,466,608 visitors (4.1% of total), who viewed the production guide, were twice as more likely to buy Nudie jeans product, than they were before reading production practices of the company.
Gils, M. V.	Position Paper: On Blockchains. 2017	Position papers on using blockchain for FairTrade in agricultural food products by FairFood, Netherlands.	- FairFood's research indicate that, food Supply chains are inefficient which has great economic, environmental and social consequences. Farmers are paid below poverty lines and there is a growing need for sustainability in food chains. - The use of blockchain in supply chains enhances transparency to counteract food Bourne diseases. It also offers a way to prove fair trade. Supply chain governance and compliance to regulations are also made easy by blockchain technology.
Huckle, S., & White, M.	Fake news: a technological approach to proving the origins of content, using blockchains. *2017*	Theoretical research which proposes a blockchain based solution to combat fake news.	Fake news is growing globally and there is an urgent need to verify the authenticity of media sources. Authors propose a theoretical system to verify the provenance of news data based on Ethereum blockchain and cryptography techniques which includes hash functions, digital signatures and public key cryptography. The authors also believe that blockchains are better positioned than any other technology to combat fake news.

Author (s)	Topic & year	Type	Purpose and/or Findings
Grech, A., & Camilleri, A. F.	Blockchain in education. 2017	An EU report by Joint Research Centre (JRC), the European Commission's science and knowledge service on the use of blockchain in education sector, based on literature review, desk research and interviews.	The paper first explains fundamental benefits of blockchain and the potential of the technology in education sector and explain how it can disrupt institutional norms by empowering the learner. Based on authors' analysing of technology, 8 use case of blockchain are proposed in education sectors as follows: 1. Using Blockchains to permanently secure certificates 2. Using blockchains to verify multi-step accreditation 3. Using a blockchain for automatic recognition and transfer of credits 4. Using a blockchain as a lifelong learning passport 5. Blockchain for tracking intellectual property and rewarding use and re-use of that property 6. Receiving payments from students via blockchains 7. Providing student funding via blockchains, in terms of vouchers . 8. Using Verified Sovereign Identities for Student Identification within Educational Organisations
Laurent, P., Pfeiffer, T., Sommerfield, B., Willems, A., Chollet, T., Castiaux, J., . . . Sainlez, L.	Using blockchain to drive supply chain innovation. 2017	A paper by Deliotte's Supply Chain and Manufacturing Operations practice, to showcase businesses opportunities and benefits of using blockchain in SCM.	The authors evaluate various cases for supply chain traceability and also provide insight into the use of technology. Blockchain offers many benefits. Primary benefits: 1. Increase traceability of material supply chain to ensure corporate standards are met 2. Lower losses from counterfeit/grey market trading 3. Improve visibility and compliance over outsourced contract manufacturing 4. Reduce paperwork and administrative costs **Intangible benefits:** 1. Strengthen corporate reputation by providing transparency of materials used in products. 2. Improve credibility and public trust of data shared. 3. Reduce potential public relations risk from supply chain malpractice. 4. Engage stakeholders.
Lee, J. H., & Pilkington, M.	How the Blockchain Revolution Will Reshape the Consumer Electronics Industry 2017	Blockchain in Consumer electronics supply chains. Study of existing blockchain projects and startups.	The authors conclude blockchain has the potential to ensure transparency and traceability in Consumer electronics supply chains and also acknowledge the fact technology is in early stages and may not be feasible to all SCM areas in CE industry. A lack of awareness of benefits exists around businesses using blockchain technology successfully, which is needed for blockchain adoption. Getting full cooperation from participants in CE supply chains is a huge challenge companies need to consider before implementation. Benefits of using blockchain in CE: 1. Tamper-proof history of product manufacturing, handling and maintenance. 2. Digital identity for ownership. 3. Automating supply chain process with smart contract.
Mackey, T. K., & Nayyar, G.	A review of existing and emerging digital technologies to combat the global trade in fake medicines. 2017	Qualitative study of 60 papers to tackle trade of fake medicines in the global pharmaceutical industry.	Globalisation in medicine supply chain has brought in challenges of counterfeit drugs specially in developing countries. The Global problem of counterfeit medicines is affecting developed and devoting nations alike. The use of Blockchain could potentially transform drug supply chain into a more trustworthy, accountable, and transparent shared and open data architecture. The use of RFID technology and mobile devices is highly recommend by the authors as the two technologies have matured enough.

Author (s)	Topic & year	Type	Purpose and/or Findings
Petersen, M., Hackius, N., & von See, B.	Mapping the Sea of Opportunities: Blockchain in Supply Chain and Logistics. 2017	Survey to identify opportunities and barriers in SC&L. Participants are consultants in the field of SC&L from Germany, US, Switzerland, and France.	The paper presents applications of blockchain technology for supply chain and logistics in the flooring three clusters: 1. Product tracking 2. Product tracing 3. Supply chain finance The authors also argue companies should get their own first-hand experiences with blockchain technology through small-scale experiments, which are vital to understand the benefits and challenges of using the technology.
Stein, T.	Supply chain with blockchain —showcase RFID. 2017	Study on Garment manufacturing using data from practice.	The author provides an example use case of blockchain and RFID in garment manufacturing. The RFID chip is activated and handed over to the manufactures, who embed the chips in the garment . The garment is then manufactured, packaged and fed into the supply chain. Due to the use of RFID every garment has a unique id, which provides traceability by means of blockchain technology. Advantages: Tamper-proof data, security of data and eliminating human intervention where possible.
Tian, F.	An agri-food supply chain traceability system for China based on RFID & blockchain technology 2016	Qualitative and based on published literature. Food industry in China	Tian (2016) proposes a blockchain system to induce food safety in Chinese food markets. The study presents utilisation of RFID and blockchain technology in building a traceability system. The system is also contrasted against centralised system. **Advantages**: effective tracking and traceability management, enhance the credibility of food safety information and detecting fake products. **Disadvantages**: High cost of RFID and immaturity of blockchain technology
Toyoda, K., Mathiopoulos, P. T., Sasase, I., & Ohtsuki, T.	A novel blockchain-based product ownership management system (POMS) for anti-counterfeits in the post supply chain. 2017	POC using Ethereum Blockchain to manage ownership of assets in supply chains.	The authors present us with POMS system, built with the use of RFID and Blockchain Technology, to detect counterfeit products. A proof-of-concepts is presented using Ethereum blockchain where the buyers are able to verify product authenticity and proof of ownership, by reading data from the blockchain linked with associated product's RFID tag. The cost of gas consumed on the ethereum network is around USD 1 for 7 transactions, which is very low in the opinion of the authors. The proposed System is applicable to expensive products, for example, with selling price more than USD $100. The authors also mention that, in practice, inexpensive products are not worth to be counterfeited. This kind of system clearly not suited to food products.
Fowler, M. D.	Linking the Public Benefit to the Corporation: Blockchain as a Solution for Certification in an Age of Do-Good Business. 2018	Literature review and case study of existing Proof of concepts.	The Volkswagen scandal is referred to as "greenwashing" and with "fairwashing", which shows information asymmetry preset in the market that hinders verifications of claims made by organisations Consumers and Investors demand social responsibility from companies and it important now so more than ever that there is a mechanism to verify claims made by companies. Blockchain offers accountability has become important in businesses.

Author (s)	Topic & year	Type	Purpose and/or Findings
Kshetri, N.	Blockchain's roles in meeting key supply chain management objectives. 2018	Case study of various blockchain projects.	This Author shows how blockchain can contribute to key supply chain management objectives such as cost, quality, speed, dependability, risk reduction, sustainability and flexibility. There is a severe lack of transparency and accountability across complex supply chains. Blockchain most likely to impact food industry. NGOs and organisations that monitor the fair-trade use "antiquated" techniques.
Litchfield, A., & Herbert, J.	ReSOLV: Applying Cryptocurrency Blockchain Methods to Enable Global Cross-Platform Software License Validation. 2018	Theoretical model to validate licenses using blockchain technology to reduce software piracy.	The paper presented a decentralised peer-to-peer system to solve the problem of software piracy by using blockchain technology for software license validation. The proposed models requires building a blockchain and offers following advantages: 1. Each software license is hard to copy as its guarded with owner's private key 2. Software licenses can be easily validated 3. No single point of failure. 4. Software licenses cannot be regenerated 5. Removes the possibility of man-in-middle attacks.
Restuccia, F., D'Oro, S., & Melodia, T.	Securing the Internet of Things: New Perspectives and Research Challenges. 2018	Privacy and security concerns in IoT using Literature and industry insight in the US.	IoT is revolutionising society and industry with the help of interconnected devices that gather data and communicate independently. Authors point at the need to secure the ever growing data gathered by IoT devices and recommends storing it on Blockchain as it guarantees protection against data tampering and can be effectively used to verify the integrity and validity of software. **Challenges:** Look out for privacy issues. One of the major weakness of blockchain is the possibility of 51% attack.
Spence, M., Stancu, V., Elliott, C. T., & Dean, M.	Exploring consumer purchase intentions towards traceable minced beef and beef steak using the theory of planned behavior. 2018	Survey to analyse consumer attitude and purchase intention of 616 respondents in north and south England, towards traceability beef products.	As per the TPB model, *attitude* was the main determinant of intention to purchase each traceable product, followed by *subjective norm* and *perceived behavioural control* (PBC). Respondents shoed a favourable attitude with positive behavioural beliefs and high trust towards the traceable beef product. Extended TBP model included habits, trust, and frequency of purchase. As per the extended model, the determinants are: *Attitude, subjective norm, production habits and origin habits.*

Table 5: List of studies include on Traceability & Blockchain in SCM.

5.2 Problems in Supply Chains

The main problem of food supply chains is the uncertainty about the safety of food products that impact social health (Aung & Chang, 2014; Choe et al., 2009). Unsafe food causes many acute and life-long diseases, ranging from diarrhoea to various forms of cancer. The cold chain is often abused, and failed compliance regarding keeping food refrigerated leads to microbial growth and spoilage of food. The authors also highlight damage to trade and tourism caused by outbreaks of food-borne illnesses. Global trade also means our supply chains span across borders and food travels longer distances before reaching consumers. The processes used to transfer food naturally consumes resources, produces carbon emissions during transit and emission of Green House Gases (GHG) in the entire food cycle are unavoidable. There is also a need for environmental solutions that impact pollution and global warming as realised by Aung & Chang (2014). Furthermore, damaged food also impacts firms economically, and consumers lose their trust in a brand.
Choe et al. (2009) noted the close relationship between risk perception of food and food purchasing patterns and believes reducing the uncertainty of consumers is vital.

Let's look at the pharmaceutical industry next where due to globalisation and increased online sales, counterfeit and fake medicine can reach and harm individuals. Although sales of these fraudulent drugs are higher in developing and low-income countries in contrast to developed nations, it is hard to ignore the fact that it is increasingly becoming a global problem, mainly, if it can cause permanent damage or result in a loss of an individual's life. The global trade of fake medicines has grown in a multi-billion dollar trade and is affecting developed and developing nations alike (Mackey et al. ,2017). Moreover, the authors have mentioned several times with the help of credible references, the need for increased governance and quality regulations in pharmaceutical supply chains, with the aim to get rid of corruption and fraud, as technology alone does not have an impact on the global problem of drug counterfeits.

Next, in the textile industry, the problem of fraud is a significant concern for brand manufacturers, where billions of dollars are on the stake as explained by Stein (2017) in a Faizod GmbH & Co.'s research & development publication. The source of fraudulent products is identified as the manufacturing in Asian countries, from where these fake products find legitimate marketing channels. Fraud in textile industry carries over to the clothing and fashion industries.

Customer electronics (CE) industry, which is enabled by a €13 trillion global trade in a complex supply chain arrangement (Lee et al., 2017: 20), lacks transparency in the supply chains spread geographically. In the words of the authors, "Customers and buyers have no reliable way to verify and validate the true value of the products and services they purchase because of the lack of transparency across supply chains". Another challenge in the CE industry is the lack of real-time data flow among supply chain experts and retail stores. Lack of verification is not just pertinent to the CE industry as the majority of consumer products today offer us no way to verify value, compliance and authenticity (Aung & Chang, 2014; Fowler, 2017; Huckle et al., 2017; Kshetri, 2018; Sayogo et al., 2018). Apart from consumers, firms also have no way to verify the self-reported claims made by suppliers regarding the social and environmental impact (Kshetri, 2018). Huckle et al. (2017) have explained the problem of fake news spreading throughout the internet, and we are unable to verify the authenticity of such content in the news & media industry. Such fake news can impact elections as it changes public option when perceived as real news. The software industry is plagued with piracy problems as software license keys are reused due to the lack of robust validation methods (Litchfield & Herbert, 2018).

Finally, in the Internet of Things (IoT), the numbers of IoT devices gathering information is growing enormously every year as is the need to keep this information secure, private and trustworthy (Restuccia et al., 2018). The growth in IoT is expected to be explosive as in the near term future as the technology is bound to be absorbed by almost every existing Industry. Hence the authors have made a strong case for highlighting the problem of keeping data from the IoT components trustworthy and secure.

In summary, supply chains can have significant social, environmental and economic impact. Supply chains lack transparency and are subject to fraudulent behaviour along with non-compliance. IoT plays an essential part in many supply chains; however security of these devices present us with tremendous concern. Moreover, consumers have no way to verify the value and safety of their product; and organisations have no way to verify compliance and claims made by their supplier and partners.

5.3 Supply Chain Traceability

As explained by Olsen et al., (2013), traceability in supply chains refers to the ability of participants to access all information regarding a product in question; and with means of recorded identifications throughout the entire life cycle of a product. A product's life cycle begins with raw materials and follows a journey through various processes before turning into a finished product and reaching the hands of consumers. Identifying a product in the supply chain and systemically recording all information regarding processes and involvement of participants throughout the lifetime of a product helps us effectively achieve traceability. Traditionally, with the use of central traceability systems, firms use traceability as an internal tool and consumers do have access to these systems. Now, the question arises whether consumers value traceability of their products and whether consumers should be part of such systems, allowing them to track the provenance of their products. The following sub-sections allows us to establish why consumers should have access to traceability systems.

5.3.1 Demand for traceability

The demand for quality and safety in perishable food items is clear and straightforward. Recent food accidents have lead to greater public and government interest in the traceability of items such as meat. A survey conducted by Spence et al. (2018) in the UK to analyse consumer intention to buy traceable beef products shows that consumers value the availability of traceability information in their meat products. Minced beef and beef steak were the two product categories analysed in this survey. According to the analysis and results of this survey, the authors reached the conclusion attitude mainly determines the buying intention which leads to the behaviour of a person buying traceable beef products. Followed by attitude, Subjective norm and PBC are the other two determinants of intention as per the constructs of the theory of planned behaviour. The authors also extended the TPB model to include country of origin habits, production process habits, food assurance habits, trust and frequency of purchase. In this extended model for minced beef products PBC is no longer a predictor and in the order of importance, attitude, trust and subject norm predict intention. In the beef steak model, the significant predictors are attitude, subjective norm, production process habits, origin habits and PBC as per their order of significance. The results show people with more positive beliefs towards traceable meat products are more likely to buy it. The survey participants believe traceable beef is more likely to be authentic, safer, of known origin and complaint with higher welfare standards (Spence et al.,2018)

Dickinson & Von Bailey (2005) surveyed consumers in UK, USA and Japan to analyse their willingness to pay for treatable. The results from their survey indicate consumers have valued traceability for a long time. Consumers are willing to pay a significant price premium for a traceable red meat, and even a higher price premium for other characteristics of red meat, namely meat safety and humane treatment of the animal. Choe et al. (2009) surveyed consumers in Korea with the goal to analyse buying behaviour with reduced uncertainty provided by a traceability system. The results show us Korean consumers are willing to pay more for food managed with the traceability system, along with a willingness to purchase more significant quantities of traceable food. Consumers valued truthful information regarding food quality and safety, and the authors noted trust between the seller and consumer is the most important mitigator of uncertainty. Therefore it is appropriate to say that there is ample demand for traceability in the food supply chains based on people's attitude towards traceable food.

5.3.2 Demand for transparency regarding Sustainable practices

The demand for products made by responsible production processes has grown significantly in the last couple of decades as pointed out by Fowler (2017). The new breed of consumers value sustainability and demand corporate social responsibility and consumers today expect companies to “engage in a more prosocial and proenvironmental manner along their supply chains”, as discovered by Fowler (2017: 917). Consumers are increasingly becoming aware of the social and environmental impact of supply chains along with poor conditions of our food producers.

Egels-Zandén & Hansson (2016) analysed customers of Nudie Jeans Co. and their online buying behaviour to determine whether transparency in supply chains can be a consumer tool which can be used to pressure companies into releasing supply chain and production information. The authors concluded that supply chain transparency is not a consumer tool and consumers do not leverage transparency with companies. On the other hand, with conclusive evidence, authors have made a strong case that transparency can be a useful corporate tool to increase a consumer’s willingness to buy. Visitors on the Nudie Jeans website who viewed Nudie’s transparency project including sustainable production practices were now twice as likely to purchase their products. This shows consumers value supply chain transparency, and it can be used to enhance their willingness to buy.

5.4 Successful Blockchain Proof of Concepts

Many successful experiments with blockchains have successfully shown the benefits of blockchain technology. Table 6 below provides a summary of some high profile POCs and startup utilising blockchain technology in supply chains. Sources of this table include published works (Petersen et al. 2017; Kshetri, 2018), a paper from Deloitte (Laurent et al., 2017), and other online sources mentioned in the table which are identified during desk research. All of these cases below are trying to solve problems encounters in various supply chains by utilising the fundamental properties of blockchains.

Project & Product	Overview of the blockchain based system and benefits
FairFood Netherlands. Coffee and Fair trade. Demo url: https://fairfood.nl/en/beanthere/	FairFood has conducted several proof of concepts to showcase fair trade in supply chains using blockchain technology. In 2018, FairFood tracked arabica coffee beans that were grown in Colombia and sold in the Netherlands with the help of a blockchain running on a system provided by BEXT360.In this system, The Coffee beans are tagged, and the information related to their movement and supply chain processes is recorded on a blockchain. This solution shows us how and on what dates coffee beans move from a farmer in Columbia to a processor who processes the coffee and records that information on the same blockchain as well. A key element to note here is the availability of price information, as the paper receipt for payment made to the farmer is also uploaded on a blockchain, in the form of an image. Moving on from processing, the beans go to a cleaner in Colombia from whom Bocca purchases beans for roasting and packaging in the Netherlands. Bocca then sells this coffee product to customers who can see the entire history starting from the point of origin from the information stored on the blockchain. Consumers can see prices paid, dates and the handling information of their coffee beans. This solution by FairFood and BEXT360 provides consumers with proof of sustainable practices.

Project & Product	Overview of the blockchain based system and benefits
PROVENANCE Fish Traceability	PROVENANCE conducted their first pilot in 2016 to showcase traceability in the Indonesian fishing industry which is plagued with corruption, lack of supervision and questionable supply chain practices leading to human rights violations. PROVENANCE deployed blockchain technology in the fish supply chain along with the use of mobile phones and smart tagging technology to enable real-time traceability of fish caught by Indonesian fishermen and the processes involved in bringing fish to end-consumers. With the success of this pilot program, PROVENANCE allows consumers to trace the origin of their fish products and address sustainability challenges in the value chain. Blockchain offers a robust to verify social sustainability claims and show provenance of products along with their raw materials.
Maersk Port Logistics covering all kinds of products. (POC in 2016)	In a successful POC conducted by the world's largest container carrier Maersk, Blockchain based traceability system can track container full of goods in the logistics and shipping sector. Maersk successfully tracked a container full of flowers from Mombasa in Kenya, to Rotterdam in the Netherlands. The system was also then used track containers of mandarins and oranges among other goods in the global shipping chain as per the evidence found. The system based on IBM's platform provided information such as GPS location and temperature of goods during shipping. The goal of this system is to reduce the shipping time by digitising paper process, which can hold a container full of perishable goods for days while waiting for paper-based approval from authorities such as tax and health. The cost of paper paperwork which is nearly the same or more than the cost of shipment was significantly reduced to 15% of the cost of shipment by storing most of the information on blockchain. Maersk was also able to include customs and other government agencies in their system, and the system produced a digitised Bill of Lading, reducing the cost of paper processing and the chance of fraud which happens by manipulation of paper-based Bill of Lading. The system makes uses of digital signatures for authentication and authorities can see and sign off on the information provided by the blockchain in a secure manner which is resistant to fraud. The real-time information is also said to have reduced processing times and waiting time for containers.
Walmart Food produce and Pork meat.	Walmart with the help of a system built by IBM has successfully conducted two pilot programs in 2016 and 2017 to showcase supply chain traceability. The first product tracked was in the form of pork meat products in Chinese markets and the second included mangoes in the supply chains leading to the US. The goal of Walmart's system is to provide food safety by detecting the sources of contaminated food and proactively acting on the information to avoid harm to public health. Walmart's results are encouraging as the system was successfully able to trace the origins of pork in China and mangoes in the US within 2.2 seconds as compared to days or months taken by non-blockchain based solutions. The information included the farm, factory, batch number, storage temperature and shipping which can be verified from immutable transactions in blockchains. To identify products and collect information, Walmart made use of RFID tags, sensors and barcodes. With the help of a blockchain based system, Walmart can address food safety concerns in the meat and fresh produce supply chains. Blockchain allows for a more effective recalling process as it provides provenance of information which can be used to pinpoint the source of a problem.

Project & Product	Overview of the blockchain based system and benefits
EverLedger Diamonds & Wine	Everledger is a startup utilising Blockchain technology to verify the provenance and sustainable practices of luxury items as Diamond and Wine. Everledger has successfully used blockchain technology to combat fraud and unethical practices in diamond supply chains. Every diamond registered with the system comes with a certificate which can be verified using data from blockchain. This use case naturally lies around the use of blockchain to store one version of truth immutably from every interaction in the supply chain, which is used to prove the chain of ownership. With the use of blockchains, authenticity and compliance with ethical mining can be verified by traders and end-buyers of diamonds. For wine traceability, every bottle has a tamper-proof RFID tag in the cork to identify every wine bottle uniquely in the blockchain. Everledger's blockchain bases traceability system collects 90 instances of data relating to owner and storage history of wine. Retailers, warehouses, auction houses and other sale platforms can now verify the provenance of wine they buy.
Modum Ambient Pharmaceuticals.	Modum successfully conducted their first pilot project in June 2016 to track ambient medicinal products that do not require refrigeration but need to comply with temperatures of 15°–25 °C while transiting. Most medicines are required to be transported in strict temperature, humidity and light conditions in order to ensure their usability. Built in collaboration with the University of Zurich, Modem's system can ensure safe delivery of pharmaceutical drugs. Every medicine product is associated with so-called "stability data" which refers that to the fact that medicine can stay for x hours in the temperature range Y, which is typically 72 hours between the range of 2 °C and 40 °C. Medicines also have to comply with the set regulatory standards in the EU. Data on the blockchain, which is taken from sensors while transit, is used to prove compliance to standards by meeting the temperature requirements. Modem's system stores the temperature of medicines frequently, however, the system is not intended to be used for medication in the cold chain. Once the ambient medicine shipment reaches its destination, the data collected by sensors is transferred to the Ethereum blockchain where solidity based smart contract compares the data from sensors to various set requirements. The products are released if data meets the set regulatory standards, and in cases where conditions are not fulfilled, both sender and receiver and notified of the deviation from the required temperature range. Blockchains allows users of Modum's system to provide proof of regulatory compliance as well as automate business processes based on smart contracts.

Table 6: Summary of successful Blockchain projects.

All the above-mentioned projects aim to solve particular problems in their respective supply chains. Experimenting with the technology in pilot phase helps identify its benefits and cost impact as in the case of Walmart and Maersk.

5.5 Primary use cases of Blockchain in Supply Chains

According to the evidence in the published works, authors advocate the use of Blockchain in supply chain management with the advice to conduct trails before going into production. Many of the existing supply chain problems can be counteracted with the use of Blockchain technology. The five main use cases identified for supply chain management are:

1. **Product tracking**: With a consistent data trail linked with a unique products, blockchains allows us to locate the products and shipments in the supply chains in real-time thus achieving traceability of products (Tian, 2016; Stein, 2017; Petersen et al., 2017; Laurent et al., 2017; Kshetri, 2018).
2. **Source tracing**: With the aid of blockchain technology, consumers and other interested supply chain participants can verify the provenance of products along with the raw materials (Tian, 2016; Petersen et al., 2017; Kshetri, 2018).
3. **Reduce fraud** in the supply chains by detecting fake or counterfeit products with the help of tamper-proof information stored on blockchain (Tian, 2016; Stein, 2017; Laurent et al., 2017; Toyoda et al., 2017).
4. The technology can be used in addition to IoT devices, which allows **verifying compliance** of food and other products by recording information such as temperature, humidity, motion, chemical composition or other relevant indicators (Tian, 2017; Laurent et al., 2017; Kshetri, 2018).
5. With the help of Blockchain, consumers NGOs can **verify sustainability claims** made by organisations (Gils, 2017; Kshetri, 2018). Kshetri (2018) also believes blockchain has the potential to end unethical practices in supply chains.

Although authors have mentioned other use cases in some papers, the above mentioned five have are supported with evidence from case studies and POCs. Interestingly the need for uniquely identifying products is self-evident for blockchains to link with supply chains.

5.6 Need for uniquely identifying Products.

Every product comes in different shapes, forms and characteristics. In order to successfully track a product in a supply chain involving numerous actor, it is mandatory to identify the product or a batch of products with the help of a single unique identifier. By doing so, we created a unique identifier of physical creates to create a link in the digital realm. Various methods used to identify products are described below from the published work of Aung & Chang (2014):

1. **Alphanumeric codes**: Numbers and alphabetical characters that make up a unique string, which can be displayed on a product to identify it uniquely. Alphanumeric codes are elementary and economical to use, however, they cannot be automated by the use of scanners and are prone to errors. Figure 8 shows an alphanumeric code that is unique to a single clothing product in the form of PRESS18KN1001.
2. **Barcode/QR codes**: These are machine-readable optical representations of alphanumeric codes that provide automation as scanners can read and interpret data from these codes automatically. Barcodes and QR codes display the unique identifier linked to a product in a machine-readable way. Barcodes are made up of

vertical bars and spaces, whereas QR codes are made up of squares, spaces and dots. These are also economical instruments that are used in the traceability of products. Reading these codes requires a line of sight and only one code can be read once. If the code label gets damaged, it becomes unreadable. Figure 9 shows an example of QR code on the left used by PROVENANCE to link a unique identifier with a clothing product.

3. **Radio Frequency Identification (RFID):** RFID chips store information about the product identifier and communicate with a reader via radio waves. Scanners can detect the presence of products tagged with RFID chips. RFID chips are useful as they can store more data, don't require line of sight and multiple tags are read simultaneously. Many mobile devices are equipped with NFC which can also be used to read tags using a mobile phone. Using RFID chips is an expensive solution when compared to the cost of using QR codes. Figure 9 shows RFID chip on the right, which is used by PROVENANCE to store the same unique identifier as in QR code.
4. **Wireless sensors:** These are expensive units that can sense data from physical or environmental conditions and have a more extended range. Sensors are particularly useful in food traceability where temperatures can be recorded to ensure compliance of food products during transit. Sensors can communicate over a network which makes them better than QR codes; however, they are not feasible for identifying a product as they require a battery to power them. Energy saving techniques are required to prolong the lifetime of an RFID tag. The use of sensors solely for identification purpose is not recommended.

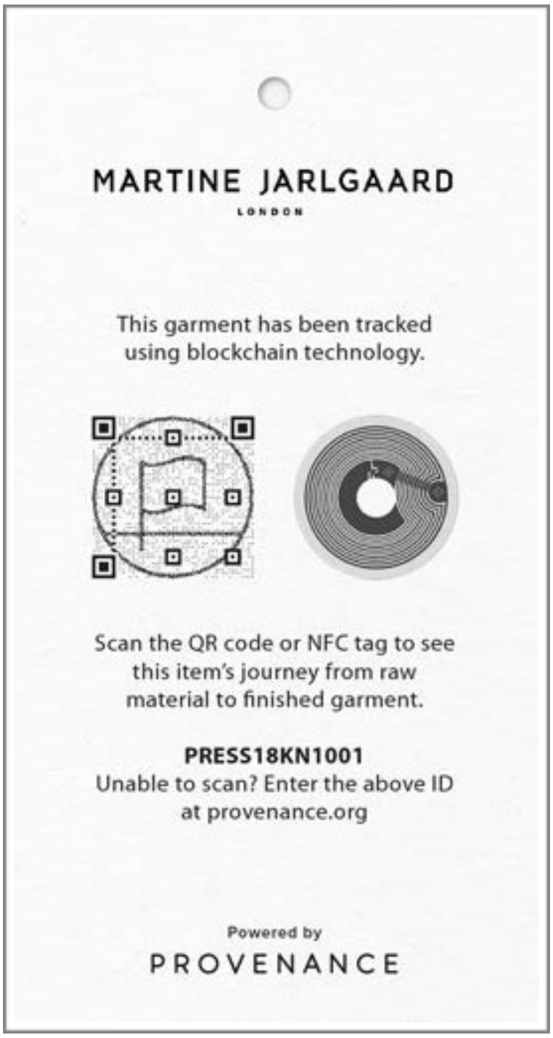

Figure 8: Example of tags. Source:provenance.org

5.7 Opportunities in SCM

Blockchain helps eliminate the need for paper transactions which significantly impacts industries such as port shipping where paper cost is notably high. Blockchain offers a way to induce supply chain efficiencies which greatly benefits traceability systems by having the most accurate information in real-time. It is of particular importance in the food industry where due to the fragmentation of data among various parties, it is hard to track the source of contaminated food. As explained by Kshetri (2018), Walmart can trace the source of pork and mangoes in 2.2 seconds rather than days. Plenty of research has shown traceability reduces buyer uncertainty which brands can take advantage of by enhancing consumer trust, particularly toward food chains. Proof of origin and compliance reduces the buyer's perceived safety risks in the food sector. It is possible to use blockchain for traceability of products and transparency regarding sustainable practices.

Competitive advantages and reducing costs is another opportunity presented by blockchains. Cutting down middlemen, quicker information sharing and security are some aspects which lead to lower costs and optimisation of business processes that can be tested in POCs. Walmart and Maesrk have successfully shown what benefits they have achieved with the use of permissioned blockchain technology. Proving supply chain compliance and auditing would also become more accessible with the use blockchains and firms can have better control over outsourcing. Fraudulent behaviour is bound to be highlighted more so than earlier with the use of cryptography which is particularly important in industries where counterfeits are on the rise. In a nutshell, the technology offers a way to store validated supply chain information in a secure and trustworthy manner and the information stored on blockchain can be verified at any time by all participants and used efficiently for decision making.

5.8 Concerns and Challenges

Despite its many advantages, it is not straightforward to implement and start using blockchain in the entire supply chain network. As highlighted by Lee et al. (2017), in the case of consumer electronics sector, full cooperation is required by all stakeholders to adopt blockchain, which the authors have described as a more substantial challenge than the technological viewpoint. It is clear that data is required from all processes along the supply chain to achieve traceability; therefore, a participant's willingness to cooperate plays a significant role in the success of such systems. Furthermore, the cost of incorporative technologies, such as RFID and IoT devices cannot be overlooked and can have a significant cost impact on a business. Security of these devices should also be considered of prime importance as it can hamper the integrity of data supplied to the blockchain. Petersen et al. (2017) have suggested from their findings, performing small-scale experimentation to understand the benefits of using the technology in supply chains.

It is also clear that the technology is in primitive stages, so there is an apparent lack of resources available, which is why businesses are also waiting to see success stories before investing into the development of blockchain applications. Furthermore, there is an apparent lack of evidence to quantify the economic impact of the using blockchain in supply chain networks. Data from works of Petersen et at. (2017) shows organisations in logistics expect fewer benefits and more showstoppers in the use of technology. The lack of regulations around the use of blockchain further adds to the uncertainty about its use in the author's opinion.

Security of assets in the logistics process is also another challenge, for example: if containers in the middle of the sea are attacked by pirates who dig holes in the container to replace products with rocks, Blockchain is unable to identify such a situation, and therefore other security measures are mandatory depending on the complexity of supply chain. Blockchain only maintains the integrity of information stored but does not guarantee the security of physical assets in case of theft and sabotage.

5.9 Conclusion

In summary, it is safe to say there is plenty of demand for traceability and sustainability in consumer supply chains. This chapter looked at opinions from various authors to conclude that demand for transparent supply has grown considerably over the recent years with more and more consumers interested in knowing the story behind their products. The emergence of socially and environmentally responsible practices along with fairly traded goods cannot be ignored today as consumers lay heavy emphasis on these attributes.

It is also evident that supply chains in various industries are full of problems as discussed earlier in this review. Food safety and spoilage are significant concerns which can be controlled using blockchain technology. Tracking the source of a contaminated food item can take weeks today; however, with the availability of real-time supply chain using blockchain, it would take seconds to identify such problems using the trusted information trail, as seen in the case of Walmart. Incorporating IoT devices in food supply chains would also aid in recording compliance information on to the Blockchain automatically with the help of sensors that can record a variety of information such as temperature and humidity.

Blockchain technology is also instrumental in identifying fake and counterfeit products such as medicine or luxury goods. By linking unique identifiers to physical products their origin, movement and compliance can be tracked all along the supply chain by retrieving this information from the blockchain. The information stored on a blockchain is conclusive, and the technology has the potential to bring transparency along with enhancing capabilities of existing traceability systems in supply chains..

Chapter 6. Using Blockchain in SCM

In this chapter, the use of blockchain in supply chains is described from a technical point of view, and the chapter also describes design decisions needed to establish the network architecture. Experts practising in the industry have helped immensely in shaping the solution. It is also worth noting the use of blockchain is suggested both by experts and researchers, to start with small-scale experimentation also known as a proof-of-concept (POC) or pilot programs. This initial phase helps prepare for deployment in real-world usage by testing the technology in a controlled environment first. Besides, pilot programs highlight design trade-offs that can be made before putting the technology into practice. It is strongly advised to test the benefits of using blockchain technology with the implementation of a proof-of-concept. Although this chapter cannot be treated as a proof of concept on its own, it provides a foundation for creating such programs.

One way to do so is with the use of Hyperledger Fabric or referred merely as Fabric hereafter. Fabric is one of the open source projects in Hyperledger Project developed by a collaborative and open source effort from the industry which allows for the sound development of blockchain systems to suit various needs of a business network. Fabric is also a permissioned blockchain solution, which is preferred over public permissionless blockchains particularly for supply chain management, as permissionless blockchains fail to provide the desired confidentiality and scalability needed. The Hyperledger community has recognised there is no one solution which fits all scenarios and designed a modular architecture for flexibility. The use of Hyperledger Fabric is also extensively covered in this chapter. Before describing the solution, steps that are needed for implementation are outlined first starting with identifying goals first.

6.1 Identifying Goals & Participants

Before experimenting with blockchain technology, related works and industry experts suggest that it is crucial to identify clear goals for a business network and why there is a need for enhanced traceability. In this phase, it is essential to understand the problems of a particular supply chain, and in addition to that, also understanding the benefits of solving these problems by defining the problems. It is also relevant to understand the product profile and means to identify individual units or batch of units. Another critical point to note what data about a specific product is will be stored on blockchain from various touch points in the chain.

After identifying goals, businesses need to carefully look at their various layers of the supply chain to identify partners and participants involved in bringing products to the consumers. Benefits of using blockchain depend on the specifics of a particular network. However, it is critical to anticipate benefits for various stakeholders and determine feasibility beforehand for creating shared value for all participants. Blockchain adds value to a network where there is an apparent lack of central agency of trust, as it provides one version of truth for all participants in a trust-less environment.

6.2 Blockchain Design

After deciding on goals, identifying supply chain network, discovering traceability needs and product identification requirements, the next logical decision is to settle on the configuration of blockchain that best suit the needs of a business. In this section, four design decisions that are instrumental in building blockchain applications are presented.

6.2.1 Throughput and latency

Building blockchain applications for supply chains requires estimating the throughput and latency required to fulfil the transactional requirements of a particular business network successfully. These are key design decisions while creating blockchain systems as suggested by industry experts. It is necessary to estimate the number of transactions that will burden the blockchain chain network as it helps in deciding which blockchain solutions is best suited. Pilot programs are a perfect way to test and estimate the throughput and latency of a solution.

Throughput in blockchain systems refers to the numbers of transactions that can be processed in a given time (usually in 1 second). The bitcoin network has a throughput of 7 transactions per second (Vukolić, 2015). It is worth noting that such low throughput in not feasible in enterprise applications which demand a higher throughput rate as per the nature of a particular supply chain. Hyperledger fabric offers a throughput of roughly 3500 transactions per second.

Latency: The time delay in finalising a transaction after it is sent is known as the transaction latency of a particular blockchain. On the bitcoin blockchain, a transaction is considered final after six block confirmations. Every block on the bitcoin network takes roughly 10 minutes, so the consensus latency of bitcoin is very high, which is around 60 minutes due to 6 block confirmations (Vukolić, 2015). On the other hand, permissioned blockchain utilising Hyperledger fabric offers a very low sub-second latency.

6.2.2 Smart contracts for business logic

After deciding about which kind of blockchain configuration is best suited to the business network, the next step is to automate the business logic in a way that is agreed upon by the network participants. Smart contracts are executed automatically on a blockchain when the conditions of the contract are fulfilled. With the use of blockchain and smart contract, business logic and manual processes in the supply chain can be automated. For Example, one version of a smart contract can be decided between a buyer and grower of food products; where once the shipment received by the buyer, the producer is automatically paid for it along with notifying relevant parties by execution of the smart contract. By identifying actual processes of a particular supply, it can be decided which of these processes can be automated by smart contracts.

6.2.3 Connecting Applications (Clients)

Blockchains networks do not provide any functionality to organisations but a way to consistently administer transactional information verified with consensus from everyone on the network. It is the applications or client applications built on top of a blockchain network that is capable of providing functionality to end consumers and other relevant actors in the supply chain. Applications are developed and owned by organisations. For example: For providing traceability services, it makes sense to create an application for customers of a brand. This application would take product ID scanned by the consumer and then connect with a peer to query information regarding the product from blockchain ledger. After which, the application displays the product information which is retrieved from the blockchain by the application. Apart from consumers, organisations can also make applications for participants to interact with the blockchain wherever necessary in the supply chain. For example, an application for shipment company, so their employees can interact with the ledger and send information regarding the shipment they handle. In the next sections, the technical details of Hyperledger Fabric are presented, detailing how to model and test business supply chain networks.

6.3 Hyperledger Fabric

This research has particularly identified permissioned blockchain technology as a solution for supply chain management. At the time of this study, Fabric[1] version 1.2 is the current stable implementation of distributed ledger technology that facilities execution of smart contracts (Cachin, 2016) with a modular architecture and pluggable industrial-grade functionality. In a supply chain network, Fabric offers various advantages to businesses with permissioned blockchain solution that can be used to store tamper-proof data and run smart contracts known as Chaincode. As per the documentation of Fabric, in most cases, organisations come together as a consortium to form a blockchain network, and the permissions to access are set and agreed by the participants when the network is built initially. The benefits and features of using Hyperledger Fabric as a permission blockchain are as follows:

1. Hyperledger Fabric offers an open source permissioned blockchain implementation with immediate finality (Cachin, 2016). It offers higher throughput and lower latency in supply chains than a permissionless blockchain solution such as Ethereum.

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[1] https://github.com/hyperledger/fabric

2. Fabric offers Identity management with Membership Service Provider (MSP) that manages access to the network and authenticates participants to use the network. Digital identities and signatures are needed to identify participants in any permissioned network. Fabric uses digital identities in the form of X.509 certificates using the traditional Public Key Infrastructure (PKI) model to ensure secure communication among participants in the network.
3. There is no single hard-coded consensus in Fabric which provides flexibility due to modularity and offers a chance to write custom protocols. Other than consensus, pluggable choices are offered in identity services and encryption algorithms.
4. In Hyperledger fabric it is possible to create a private channel from a subset of peer nodes, which allows only participants on this channel to access transactions happening inside the channel. The concept of channels allows businesses to keep sensitive information on a need to know basis. Channels are configured on the ordering service.
5. Smart contracts in the form of chaincode processes business logic automatically and in Fabric chaincode contains logic behind every transaction. Chaincode manages the ledger through transactions submitted by client applications.
6. Fabric offers persistent key-value storage with the use of CouchDB, which supports rich queries on state records.
7. Fabric provides SDK for developing applications (clients) with popular programming languages. It currently provides SDK for Node.js and Java. In the future, Fabric is also intended to include Go, Python and SDK for REST.
8. Fabric processes transactions in an efficient way. By separating the execution of transactions from ordering and validation, it facilitates concurrent and parallel transaction processing which saves time.

All the features mentioned above makes Fabric the optimum choice for experimenting with blockchain technology and creating proof of concepts. Fabric offers flexibility, confidentiality and scalability. Two main steps in bringing up blockchain systems in fabric include (1) modelling a business network and (2) creating a network to deploy model of the business network on the desired infrastructure such as a cloud. In the next two sections modelling a business network in Fabric is discussed after which an overview of network elements is presented to understand how blockchain systems are built using Fabric.

6.3.1 Modelling Business Networks in Fabric (.bna)

Modelling a real business network is easy with the use of Hyperledger composer, a toolset provided for rapidly designing and testing out business networks. A business network is a digital representation of an actual business network along with its business logic. Applications consume data from the network once the defined business network is deployed in a production environment with instances of actual participants and assets. The composition of a typical business network archive (.bna) is made up of the following four components packaged into a single file:

1. **Model file(.cto)**: The model file contains the data model for resources of a particular business network. The model of data is created using an object-oriented Composer Modelling Language, which is used to define the structure of resources that are stored in a ledger, or processed as transactions. In addition to defining the structural model, it also defines the relationships between various elements. The three following types of resources can be defined inside a model file::
   1. **Assets**: Anything with monetary value that is exchanged with network participants can be modelled as an asset in Hyperledger. Products such coffee beans can be modelled as assets after which instances can be defined and stored using key-value pairs in JSON or binary format. Assets can be tangible such as clothes, perishable food products, medicine, raw materials; and also intangible such as contracts.
   2. **Participants**: Any actor in a supply chain is modelled as a participant. The model contains properties that are recorded for each actor in the network. Participants are included along with assets in the .cto file. Various types of participants can be modelled to suit the needs of a business network. Some example of participants are farmers, retailers and deliverers.
   3. **Transactions:** Transactions that are bound to happen in the network are also modelled in the .cto file. For example a transaction for receiving a shipment.
   4. **Events:** Events create a notification and can be modelled to reflect a change in the ledger. Events are emitted by transaction processors to notify external systems of a significant update. E.g., notifying the relevant parties upon receiving the shipment.
2. **Script file (.js)**: After having desired models in place, smarts contracts in the form of executable transaction processors are created in using javascript which essentially defines the business logic. E.g., Logic behind shipment received transaction can be found in the script file of the .bna.
3. **Access control rules (.acl)**: Different participants in a business network are needed to have appropriate access based on their membership in a permissioned network. The level of access for various participants is to be described inside .acl by creating access control rules.
4. **Query definitions (.qry):** Queries that apply to a business network reside in the .qry file which is also optional. Queries are defined particularly to extract data from the word state database in blockchain ledger of a business network. A query

can also have variable parameters to facilitate customisation. Access control is also applicable to queries and users will not be shown data they are not authorised to access.

6.3.2 Hyperledger Fabric Network Components

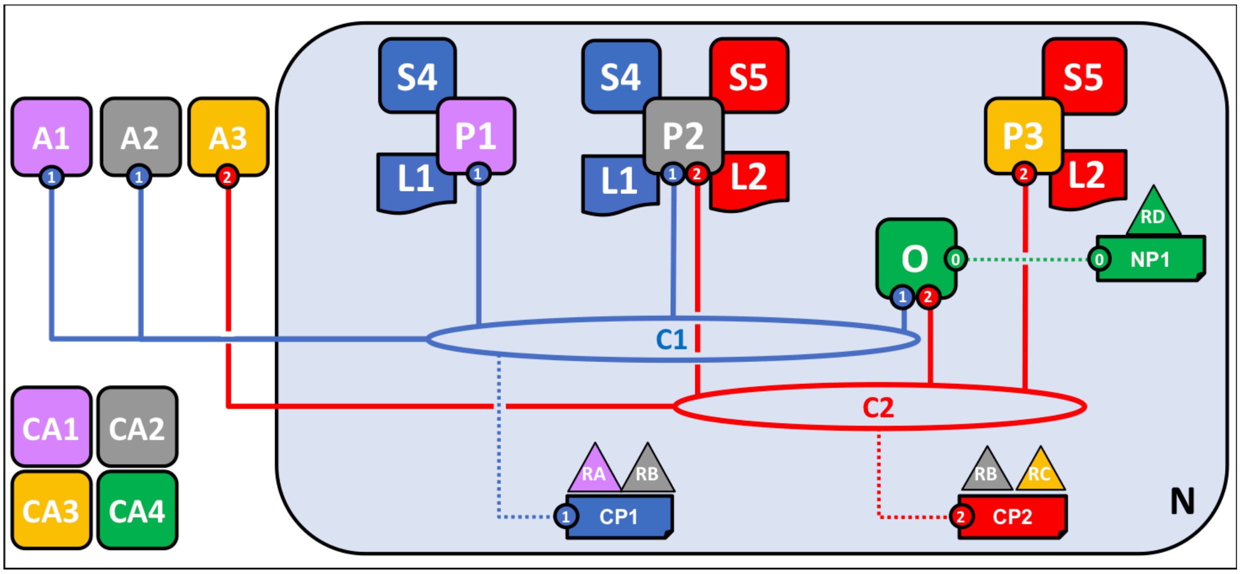

Figure 9: Hyperledger Fabric network components. Source: Technical documentation

Hyperledger Fabric network refers to the technical infrastructure needed to provide blockchain service to applications and administrators. Such network typically consists of two or more organisations coming together as a consortium. The consortium decides the access to such a permissioned network in the form of policies that can be updated at any time but only upon agreement between consortium members. The elements of a Fabric network are explained next to gain an understanding of what is required for setting up physical infrastructure. These are as follows:

1. **Peer nodes** or peers are the fundamental network entities in a blockchain network that are owned by organisations and serves them with a point of connection to the blockchain network. Peers are denoted as P1, P2 and P3 in the above Figure 9. A blockchain network in Fabric constitutes of a bunch of peers that collectively form a network. Peers host ledgers and the corresponding Chaincode that is used to access and update the ledgers.For Example L1 and S4. A peer in a Fabric implementation provides flexibility of adding one or more ledgers per channel. Applications connect to peers through their available channels to read or write transactions. Peers also have an identity in the form of a digital certificate, so it can be recognised which organisation owns the peer. **Endorsing peers** are defined in the policies as the peers that execute the incoming Chaincode transactions by adding an endorsement to the transaction and returning it to the client applications. **Committing peers**, on the other hand, validate block of transactions that are sent to

them by the ordering peers, upon which the validated block is appended to the ledger resulting in an updated state. Since all peers maintain the latest copy of blockchain, every peer can be regarded as a committing peer.

2. **Ledgers**: A ledger in Fabric is referred to the data is composed of two elements. First is a world state that holds current values of all state variables. Second is the data structure that contains transactions packaged in blocks and linked to each other using a cryptographic hash. Transactions in blockchain ledger are used to modify and calculate the world state values, which can be easily queried by applications.
3. **Chaincode**: Smart contracts in Fabric exist as transaction processors which are known as chaincode and ledgers are accessed through the logic contained in chaincode. Rules for reading and writing transactions to the blockchain exist inside chaincode. Endorsement policies are also defined inside chaincode, which describes a set of endorsers needed for every type of transaction.
4. **Ordering service(s)**: Ordering service is the starting point for any Fabric network which initially defines the configuration of channels in the network. An ordering service is a collection of nodes that are responsible for ordering of transactions and packaging them in blocks. The ordering service also contains cryptographic material in the form of identities for each member on the network. A Fabric blockchain network needs at least one ordering service to function.
5. **Channel(s):** Channels create a passage for communications between peers nodes, applications and the ordering services. An application can only connect to peers and ordering service that is on its channel. Channels are configured on the network policy that exists on ordering service and contains the entire configuration of a channel. A network can have many channels as per confidentiality requirements of consortium. Every channel has a blockchain ledger attached to it, which is accessible by peers and clients on that channel.
6. **Fabric Certificate Authorities:** The use of CA is crucial in a permissioned network and serves as a way to identify and securely communicate with participants over the network. The Hyperledger Fabric CA issues one Root certificate to every participating organisations in the network and it issues an enrolment certificate for every user.

All the components mentioned above form the basis of any blockchain network created using Fabric. To understand how organisations can set up a blockchain network and channels within that a network, an example network formed as a consortium between four organisations is presented in the next section.

6.3.3 Transactions in Fabric

There are two kinds of transactions designed for a Fabric network:

1. **Deploy transaction**: This type of transaction is used to deploy a new Chaincode on the blockchain, and it takes a program as the parameter. The success of deploy transaction results in a Chaincode deployment on the blockchain.
2. **Invoke Transactions** perform a read or write based on the access of the user and logic contained in the chaincode. Read transactions results in retrieving the desired data set from the ledger. Write transactions are executed, ordered and validated in a manner that is explained in the next section.

6.3.4 Consensus & Transaction flow in Fabric

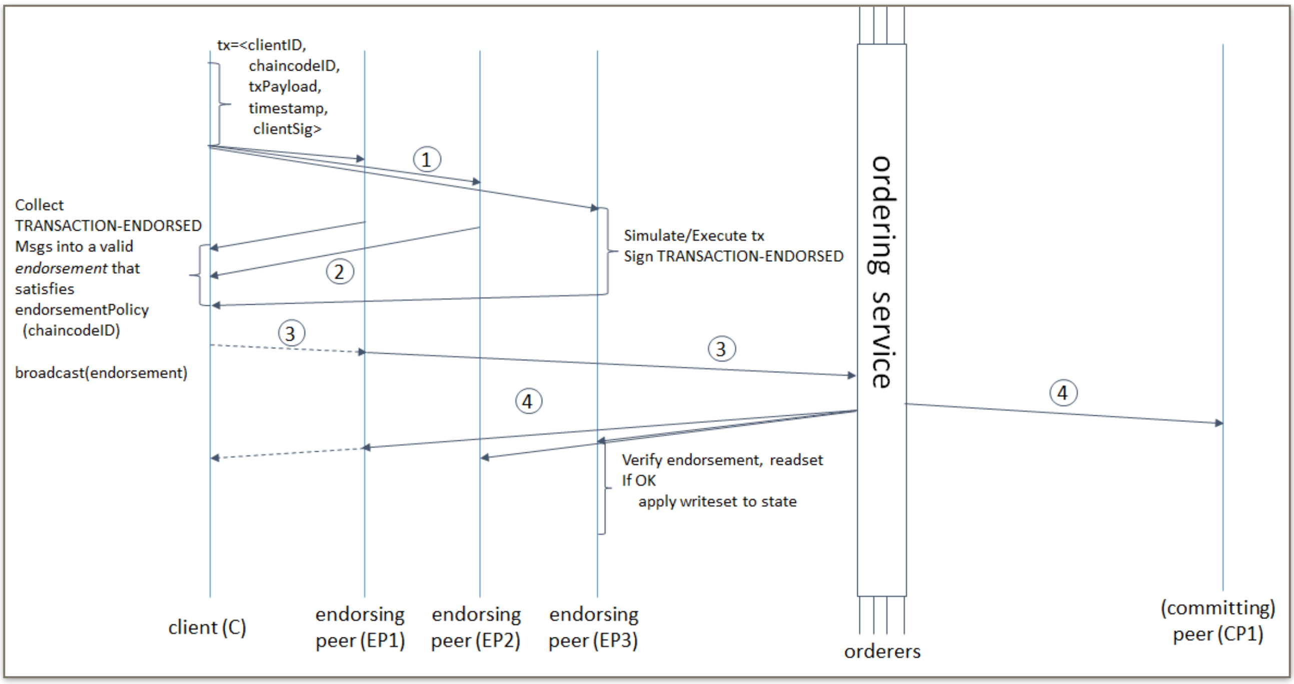

Figure 10: Transaction flow in Fabric. Source: Technical documentation

A consensus in Hyperledger provides flexibility along with higher throughput and lower latency needed for enterprise solutions. Consensus's role is fundamental in Hyperledger fabric with the help of which transactions are proposed, endorsed, ordered, and validated for committing to the ledger. It is also worth noting that consensus in Fabric is achieved when the ordered set transactions meet the criteria specified in policies, which are then committed to the ledger. Before commitment of transactions, the ordering service also guards against double spend operations and other such attacks. Invalid transactions are not added to the blocks but can be saved for auditing purposes. Fabric provides a Crash Fault Tolerant (CFT) ordering service currently, and Byzantine Fault Tolerant (BFT) service will be introduced soon. Sequence diagram in Figure 10 above shows transaction flow in Fabric network and how consensus in Fabric network is achieved:

Before describing the flow of transactions, note that the example network above contains four ordering peers that a single ordering service. The network serves client application (C) and contains three endorsing peers and one committing peer. The three endorsing peers are also considered committing peers since these three peers update changes to ledger as well but have the added responsibility of endorsing transactions proposed by clients.

In the beginning, transactions are proposed by clients as per the need. Clients have the necessary permissions set and cryptographic identities in place. In Step 1, Client connects to three endorsing peers available on its channel and proposes transaction for endorsement. The transaction includes a client's digital signature, the ID of the client, timestamp, the ID of the Chaincode it belongs to and the transaction payload. The endorsing peers execute the incoming transactions by first checking if the transaction proposals are well-formed and whether or not they have already been submitted. It then verifies the signature of the client and checks if the client has the required permissions. The endorsers then simulate the proposal by invoking the corresponding Chaincode which processes the transaction. This process then produces a readset and writeset against the current ledger state in a response, which is sent back to the client along with the signature of the of endorsing peer. No changes have been committed to ledger until this moment, only a proposal for writing changes which is endorsed has now been sent back to the client.

In step 2, the client application receives endorsed proposals responses from all the endorsing peers (EP1, EP2 & EP3). The application then verifies if all the returned proposal responses are same and also determines if the endorsement policy has been met. The changes will only be committed if the transaction proposal has the required number of endorsements as specified in the endorsement policy.

After establishing all that, In step 3 the application sends the transaction proposal along with the endorsed responses to the ordering service. The ordering service packages transactions chronologically in a block, that is ready for committing to the ledger upon validation.

In step 4, the blocks are delivered to the committing peers to make a ledger update, where the transactions are validated first by making sure the endorsement policy is met and also making sure no changes made to the state for readset since the generation of readset during execution of the transaction. Based on this criteria, the transactions are then marked valid or Invalid. After which the peers add the validated block of transactions and make changes to the ledger state from the provided writeset, and the application is notified of these changes permanently recorded on the ledger.

The above description shows the process of writing data to a ledger. In the case of just querying data from already existing transactions, the chaincode in step 2 sends the result of a query based on blockchain ledger

6.4 Case of Banana Supply Chains

First of all, the food industry is chosen to showcase traceability in supply chains as perishable food products impact consumer health and revenue of a business. Other consumer products such as clothing and luxury goods do not impact the health of consumers and offer lesser perceived risks to health. From the five mentioned use cases in **Section 5.5**, three use cases are addressed by the theoretical system presented in this chapter. The system shows two use cases of how traceability concerning product tracking and tracing the provenance can be achieved in practice. In addition to that, the proposed system shows how sustainability and other product claims can also be verified on top of traceability. Fair Trade and organic characteristics are taken as an example as these traits can be linked to bananas. The availability of information regarding processes undertaken in the banana supply chain also makes its a viable case to showcases traceability. The case of coffee is not chosen, as various organisation have already showcased coffee traceability with blockchain. FairFood.nl and BEXT 360 are examples of systems where coffee traceability is achieved. Table 7 summaries three factors considered for justifying the case for food chains.

Product Category	Impact of Traceability	Willingness of participants to share data	Information regarding supply chain processes
Food	Significant heath and economic. Compliance to regulations needed.	Yes, as observed in case of Walmart, PROVENANCE, along with the opinion of Expert **[E1]**	Information discovered for Coffee and Bananas.**[1]** **[8]**
Pharmaceuticals	High - Health and economic.	No due to fear of loosing competitive advantage **[E1]**	No Information discovered
Clothing	Low - No health Impact.	No, due to multiple tiers of sub contracting often intended to be kept hidden by firms.**[6]** **[7]**	Little information regarding processes in garments and textiles shown by SOMO.nl **[6]**

Table 7: Criteria for case evaluation. Created by Author

Red boxes show negative factors and green boxes show positive factors.

6.5 Solution: Fair Trade Bananas on Blockchain

In this section, a theoretical system is presented showcasing the use of permissioned blockchain technology for Fair Trade proof of compliance and traceability of Bananas.

6.5.1 Goals of this system

The following are the goals of this Fair Trade network:

1. Allow participants to locate the products, bananas in this case, at any point (location), and at any given time in the supply chain.
2. Allow consumers and other interested participants to trace the provenance and source of Bananas.
3. Allow consumers and other interested participants to verify proof of FairTrade compliance and organic trait of bananas.
4. Allow FTO to monitor compliance to Fair Trade throughout the supply chain.

6.5.2 Participants in this System

The following participants are associated with banana supply chains:

1. **Grower or Producer**: Banana farmers who find their livelihood in cultivating and harvesting bananas. Growers then take their produce of bananas to the cooperative to sell at a fair price including a price premium, where bananas are readied for shipment.
2. **Shipper**: Bananas are then taken to the shipping company to be fed into the global supply chain via port shipping of choice registered on the network.
3. **Distributor**: Distributors in this system, collect banana shipments from the port and initiate the ripening to ready the bananas for sale to the retailers.
4. **Retailer**: Participants who buy and stock ready to sell bananas for their consumers.
5. **Consumers**: End-consumers buy bananas from their local retailer such as Albert Heijn.
6. **Fair Trade Organisation (FTO)**: An organisation upholding the values of Fair Trade and providing certifications based on regular audits and compliance to fair trade model. In this system, Fair Trade compliance is continuously monitored by the FTO. A Blockchain network operator is also appointed by FTO to define, create, manage, and monitor the blockchain network.

6.5.3 Information model

In blockchain based systems, information is added to a single identical ledger on every peer in the form of transactions, which also represent actions taken by the participants involved. Transactions can store different types of data to represent information from various processes that are incurred during the transition of goods to final products. In the case of Bananas, the following table represent the actions of the entire group of participants with the type of data that is needed. The only major process in the banana chain is the ripening of bananas which takes about seven days. Other processes include handling of bananas, packaging, shipment, transit, receiving and sale to consumer. The information stored on the blockchain can then be used to generate a Fair Trade report for every banana, linked with a unique barcode that tells the entire story of bananas based on the tamper-proof transactions. The actions from participants together with the information captured all along the supply chain help us effectively achieve traceability of Bananas. FTO has access to much of the information for auditing purposes and therefore not enlisted below, while other participants can see information regarding products linked to them.

Actors	Actions	Information needed	Unique identifying unit
Banana Farmers	- Register Bananas - Package Bananas - Execute trade	- Name and address of farmer - Banana Field location - Harvesting date - Packaging date - Quantity - Organic or not	Box identifier.
Shipper	- Shipment received - Shipment in Transit - Shipment arrived at destination - Shipment sent	- Name & details of Shipper - Dates - Prices paid	Box identifier and Container identifier.
Distributor and/or trader	- Initiate trade - Shipment received & Transfer ownership - Start Ripening - Ripening finished - Sent to Retailer	- Name, address, processing capacity and other details of a distributor - Date - Quantity - Prices paid - FairTrade or not	Box/pallet identifier.
Retailer	- Bananas received & Transfer ownership - Generate Certification - Bananas Sold	- Name and details of retailer - Dates - Quantity - Price paid	SKU linking bananas to their boxes.
Consumers	- Verify product traits	- Date of purchase - Quantity - Price paid	Uniqe ID or Barcode linked to trade units starting from Farmer.

Table 8: Participants, actions and information required for Traceability. Created by Author

6.5.4 Assumptions of the model

1. The system is indented for small banana producers who cultivate their own land which is largely the case in Fair Trade networks.
2. The banana farmers in a Fair Trade supply chain come together to form a cooperative for the aid of farmers and which also serves as a point of sale to traders and distributors in the global supply chain.
3. The FTO provides digital identities for all participants included in the network and records relevant information regarding them on the system after initiating it. The FTO registers characteristics of participants such as “organic grower” and can change this status of participants based on auditing.

4. The FTO also lists prices of bananas that constitutes of the fair trade model. Trades that comply with the price, automatically are classified as fairly traded bananas which can be generated before selling to consumers.
5. The FTO chooses one or more trusted CA(s) to be used in the network for dispensing digital certificates and identities.
6. The choice of consensus is based on the faults a particular can handle. In this case, if the FTO is confident that more than 1/3rd participants would not collude, any PBFT based algorithm can be used to achieve consensus.
7. Every transaction needs two endorsements for trust, which can be increased in production to induce more trust.
8. Participants make use of private keys for authentication.

6.5.5 The Infrastructure model

The following Figure 11 shows us how various network component come together to form a blockchain network of interconnected Peers, Applications and Ordering service on a single channel. For the sake of simplicity, every participant has one Peer.

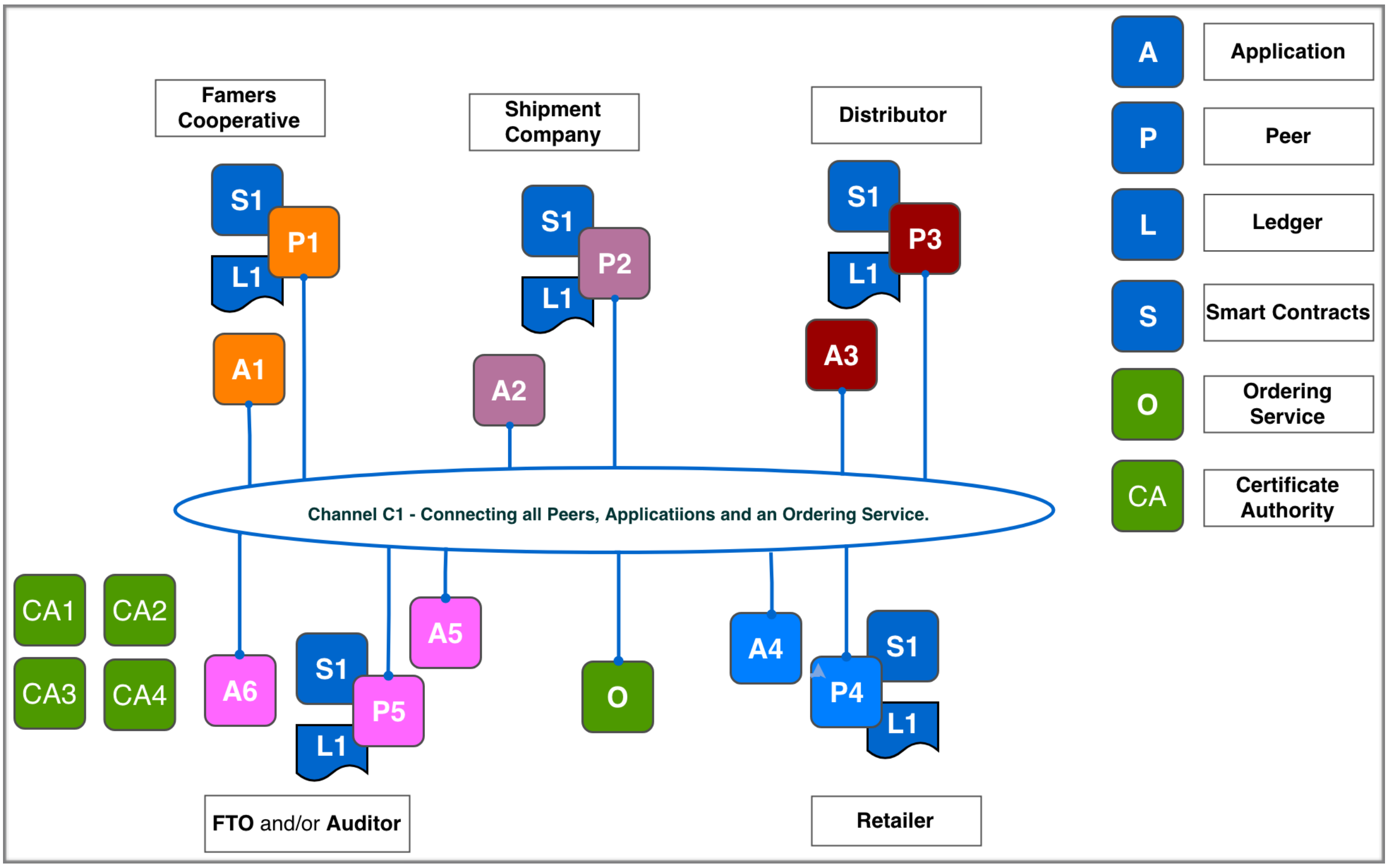

Figure 11: Infrastructure model of a Fabric based Blockchain network. Created by Author.

Every Peer (P1-P5), managed by various entities individually, contains an identical copy of the Ledger (L1) which is consistent throughout the network. The ledger (L1) is accessed through Smart Contracts known as Chaincode (S1), installed on every peer. The logic behind transaction processing resides inside the Chaincode (S1) which is necessarily the same on every Peer to enforce the same set of rules. Chaincode (S1) also limits participant's access based on role. Applications (A1-A4) are used by various participants in the chain to interact with the blockchain network as per their role. Consumers do not need a Peer, the Application (A5), made for consumers is provided by FTO, who also has Application (A6) to monitor compliance from members in the network as well as conduct audits and other needed functionality.

6.5.6 The Protocol

The following protocol is based on Hyperledger architecture and shows how transitions can be validated to avoid the fraudulent behaviour. The protocol is based on the sequence diagram presented in Figure 10 and shows the process of adding any transaction to the ledger.

1. **Initiate transactions**: Every supply chain participant makes use of the application that interacts with the network to initiate a transaction by connecting to the endorsing peer first. The communication between client application and the peer is always digitally signed for security and authentication, and this also applies to every communication on the network. Transactions in this network need two endorsements; therefore the application will first connect to two or more peers requesting execution and endorsement.
2. **Execute transactions**: Once the transaction request is received by endorsing peer, a transaction is executed against the current ledger based on logic in Chaincode to produce a readset and writeset as explained earlier in this chapter. The peer also verifies the digital signature of the client and makes sure the transaction is well-formed. The changes represented in readset and writeset are not added to the ledger but added to the transaction and the proposal is sent back to the application along with an endorsement from the peer highlighting the changes which will affect the ledger.
3. **Receive & check Endorsements**: Once the application has received two endorsed proposals on the transaction including readset and writeset, the application determines if the proposals match, in which case the transaction is ready for ordering.
4. **Ordering**: The transaction proposal is now received by the ordering service, which packages the incoming transactions in blocks as there can be more than one transaction. After that, the blocks are sent to every peer for an update to the blockchain ledger.
5. **Validation and Commit**: Next, the transactions inside incoming blocks are validated by every peer before committing to the ledger. It is essential to validate

transaction by checking digital signature and required endorsements before we commit and make a transaction permanent. Invalid and fraudulent transactions are discarded in this step.

6.5.7 Limitations

Although the proposed system can provide us with consistent information from all processes regarding Bananas, the system is still vulnerable. A centralised system is prone to a single point of attack; however, an attack on all five peers will bring this system down as well. Therefore as the network grows and more peers are added, there is a lesser chance of sabotage due to a larger number of peers. RFID should be preferred over QR codes, as QR codes can be copied and duplicated on other products. Blockchains still require human intervention to devise countermeasures against such attacks. There is also a need to trust the governance and dispute handling in such systems which again places trust on a handful of entities. In short, there is still some degree of trust required in permissioned blockchains. For Instance, we need a trusted Certificate Authority in a permissioned system for dispensing and maintaining records of digital certificates.

6.6 Conclusion

Experimenting with Blockchain is the best way to determine its feasibility with any business network. Open source technologies like Hyperledger provide a perfect way for testing out the technology to realise supply chain goals. Blockchain adds visibility to supply chain activities and products which allows for reducing consumer uncertainty, by providing buyers with proof of provenance, compliance, safety and authenticity. The use of blockchain is recommended where information is needed from various sources in the chain and where inconsistencies arise in supply chain information.

Chapter 7. Conclusion

Main Question:

How can we achieve end-to-end traceability and transparency in banana supply chains, along with creating verifiable certifications of Fair Trade and organic bananas with the use of permissioned blockchain technology?

By identifying a product uniquely throughout the supply chain and constantly storing information from all processes during a product's lifecycle on to a blockchain ledger, including information about the role of participants, effectively allows us to achieve end-of-end traceability of bananas as shown in the solution available in Chapter 6. The transactions are also validated before they become permanent to avoid fraudulent and incorrect actions. Once the information is on the blockchain, it is permanent and resistant to unauthorised modifications, and the same information can be verified at any time in the future. When such a system also connects consumers to the information regarding their product provenance and compliance, it offers them a means for verification before making a purchase which can be trusted due to the role of Blockchain in keeping information safe.

That said, blockchain may not be economically feasible in every supply chain, so a thorough evaluation of the current supply chain is advised along with recognising incentives. It only makes senses to use blockchain when multiple mutually mistrusting parties want to exchange useful supply chain information (Wüst et al., 2017). As explained by the authors further and experts interviewed, if there is only one entity that writes supply chain data to the blockchain, a regular database would be better suited instead of using blockchain in this scenario as it provides lower latency and higher throughput than a blockchain. This also makes sense as the source of information is internal which can be trusted; therefore blockchain is not the optimum solution for every supply chain.

RQ-1:

Is blockchain effective in tracking products all along the supply chain?

Blockchain is only successful in maintaining the integrity of its stored transactional data. The technology makes sure information stored is immutable and resistant to any unauthorised modifications which can happen in the case of centrally controlled databases. That said, traceability of a product is entirely dependent on the successful identification of the product in the digital realm and accuracy of information collected from various sources. All the data and transactions from a product's lifecycle are associated in the blockchain ledger with a unique identifier. In order to identify products in a blockchain ledger successfully, products are tagged with an RFID chip or a QR code which is affixed to a single product or a combined bundle in cases where it is not feasible to tag every single unit. For example, coffee beans cannot be tagged individually, but luxury leather bags can be tagged individually. The success of traceability is dependent on the effectiveness of this linkage with a product. Blockchain is only useful in producing desired traceability if the integrity of these tags/identifiers can be maintained. In other words, if someone can manipulate the product inside the packaging, blockchain will not detect that and still show the product to be original as per the information stored.

RQ-2:

What are the advantages of using blockchain in supply chains?

Blockchain maintains a consistent and immutable ledger of all the transactions in a supply chain which mainly brings shared value when there are multiple actors and data can be used for efficient chain management. The benefits, as discovered during this research, with the use of blockchain in supply chains are as follows:

1. **Transparency**: Blockchain greatly increases the transparency in a supply chain where traditionally every entity maintains their own records that creates information silos. These silos are removed with the use of blockchain technology, and every participant has access to the same information, therefore, making supply chains more transparent with the visibility of information. It is worth pointing out that public access might not be in the best interest of an organisation that requires confidentiality.
2. **Enhanced traceability of products**: Blockchain not only offers a way to store immutable information, but it also provides one version of the truth to all the participants in a supply chain network. Data from various supply chain process can be captured and store in a shared ledger to determine the whereabouts of supply chain goods at all times.
3. **Accountability**: By linking digital identities with participants, administrators can detect the source of fraudulent behaviour in a blockchain network. It is practically impossible to cheat in an adequately implemented blockchain network as the provenance of information is permanently linked with the actor using digital identification.
4. **Real-time information flow**: Blockchain fundamentally keeps the most recent copy of the ledger on all peers, and the information is validated and shared in real time. Due to this fundamental characteristic of blockchains, participants can receive data updates from various endpoints in a supply chain in near real-time.
5. **Automation**: With the use of smart contracts, for example, Chaincode, blockchain can automate the business logic of a particular supply chain network. For example:

Upon receiving a shipment of fruits from a farmer, as soon as the receiver confirms receiving the shipment, blockchain can process the payment for the shipment and send it automatically to the farmers with the help of Smart contracts. Smart contracts self-execute themselves when the conditions specified in a smart contract are fulfilled.

6. **Enable new business models**: There is no doubt that blockchain will change the way business is done fundamentally by providing a decentralised approach of conducting business transactions. By eliminating the need for trusted centralised parties that are typical of our current business practices, it offers a new way to conduct business without the need of trust which unlocks new business models.
7. **Consistent audit trail**: As the data stored on blockchain is immutable, this data trail can be used to create a consistent and error-free audit report. Accurate audit trails are the means to avoid any regulatory penalty and blockchain offers a way to consistently do so.

RQ-3:

What are the advantages of using permissioned blockchain technology in supply chains?

Permissioned blockchains contain a small number of peers (peer nodes), due to which permissioned networks offer higher throughput and significantly lower latency over permissionless blockchains. Additionally, identities of participants are known in advance, so every communication on a permissioned network is digitally signed. Therefore there is no need for PoW consensus algorithm requiring massive computational resources. Permissioned networks also provide confidentiality as the information is only accessible by a handful of participants, who can be provided with information based on their role and access.

RQ-4:

How can blockchain technology be implemented in supply chains?

There are two possible ways to use blockchain technology in supply chain networks as also proposed by Deventer et al. (2017), in a paper written by TNO. The two possible strategies are broadly categorised as “Make” or “Buy”. Organisations need to establish trust concerning the governance of the source code, and the business model of the network. Who controls the source code and installs updates is an important question to ask as it could lead to abuse of the system. Here are three ways how the two strategies as mentioned above can be put into practice:

1. **Private permissioned blockchain (Make)**: As explained by the authors, for a brand which is a market leader, it makes sense to build own proprietary and private blockchain to be used be used by the owner organisation and its supply chains partners along with auditors. A traditional database may also facilitate such a solution if the organisation can trust the sources of data. The challenge here is to convince partners and come to an agreement about feeding data to the chain. On top that the organisation needs to create their governance over the network and also its source code. Apart from governance, a business model needs to implemented as well in such scenarios.
2. **Using existing blockchains implementations (Buy)**: The benefits of blockchain can be reaped by building decentralised applications on top of existing implementations of blockchain technology. There is no need for spending resources on building a blockchain network when exiting blockchain networks can be equally leveraged to manage supply chain information. Two examples of available blockchain solutions to use are Ethereum[2] and VeChain[3]. Ethereum offers a public and permissionless blockchain solutions where a small fee is charged for performing a transaction as well as a smart contract. VeChain offers blockchain-as-a-service to enterprises. It is also crucial to the study of governance as well as business models of such projects, as every project is comprised of a different approach.
3. **Consortium-based blockchain solutions (Make or Buy)**: When two or more organisations combine resources for the mutual benefit, a consortium is formed. It is interesting to note that competitors can join hands to form consortium as it brings mutual benefits to the firms and their customers. Consortium implementations offer flexibility to use one of Make or Buy strategy to suit the needs of a supply chain. Blockchain consortium can serve two purposes namely business-focused or technology-focused. Business-focused consortiums aim to solve particular business problems and are geared towards bringing technology to customers. Technology-focused consortiums, on the other hand, target the development and advancement of reusable blockchain technology. For example, Hyperledger is a technology-focused consortium formed to advance cross-industry blockchain technologies. Organisations when forming a consortium need to define and agree on the policies that govern a blockchain network. In a blockchain consortium network, organisations also commit resources in the forms of developers, peers, ordering services, Identity services; along with applications that access or update the ledger

[2] https://www.ethereum.org

[3] https://www.vechain.org

stored on peers inside a blockchain network. Its governing members decide the business model of a consortium and fees.

RQ-5:

What are the incentives for stakeholders to use blockchain technology for supply chain management?

Blockchain offers benefits for all stakeholders in a supply chain by providing greater transparency and readily available immutable information stored as transactions. It creates shared value by offering one version of the truth to all parties involved, and blockchain technology removes the need for a centralised and a trusted third-party. Often supply chain data is fragmented as the data exists in silos among various stakeholder. Blockchain removed these silos, and the benefits for various stakeholders are presented below:

1. **Producers**: With storage of information regarding their produce on the blockchain, producers such as farmers can make certifiable claims that are verifiable from the transactions stored permanently on a blockchain. Certifications such as Fair Trade and Organic is backed with immutable data. Farmers' efforts and quality of produce are better-recognised by customers with the use of blockchain technology. By eliminating mediators and other costs, there's also more economic benefit in the value chain for producers.
2. **Manufacturers & Processors**: With blockchain, manufacturers can verify their suppliers which provides greater supply chain integrity. Processors can see the lifecycle and trace of the raw materials/products they buy. Auditing is significantly improved with the consistency of data among various participants on the blockchain.
3. **Logistics**: Blockchain removes manual paper processing which is typically used in logistics today, and blockchain enhances operational excellence for logistics providers by facilitating better coordination of supply chain data with the aid of near real-time data flow among processes. Bill of lading, which is primarily used to record data about shipments on paper, can now be created digitally by recording supply chain transactions on the blockchain. The use of smart contracts in logistics also reduces manual processes thus reducing processing times.
4. **Consumers**: End consumers, with the help of applications running on top of blockchain networks, can now benefit from increased transparency and traceability. Consumers can see the journey of their products right from the origin, along with the roles of various actors and processes that are a part of its supply chain. In addition to that, consumers can also verify product compliance information reducing their perceived risks. For instance, in perishable food items, consumers can see the temperatures of food items while in transit leading to food safety. This is done through

the use of a wireless sensor that records data from its environment and records it on a blockchain automatically. As stressed enough in this paper already, once the data is on blockchain it is tamper-proof. So with the use of blockchain technology combined with IoT, consumers verify their products themselves and not have to rely on the word of a brand regarding consumer products.

5. **Auditors and Government**: Blockchain indeed brings value to auditors, inspection agencies and customs agencies as well. By adding these agencies on a permissioned network such as Fabric, they can see transactions from the supply chain network. It removes the need for manual data exchanges which saves time and effort. Regulatory authorities benefit from the data sync-and-share feature of blockchain among peers, which automatically keeps the most updated version of the ledger on their peer. Independent inspection agencies, in the same way, can be made part of a blockchain network, where these agencies can access data that would help them in performing random inspections. Fair Trade Organisations can monitor compliance from members by constantly analysing data on a blockchain rather than relying consumer complaints and information fragmented among chain participants.

RQ-6:

What are the barriers and challenges of adopting blockchain technology for supply chain management?

Apart from discovering challenges associated with blockchain in recent literature, the following barriers to blockchain adoption are presented from the practised opinion of industry experts that were consulted during this research.

1. Blockchain knowledge is expensive, and there is an apparent lack of expertise that limits its adoption in the industry. Blockchain is a new technology which is still in its infancy, so it is also essential to understand the technology fully and its impact on business before implementing. Many pilot projects end in disasters as they are are not well thought of or not done in the right way that brings benefit to a business.
2. Legacy infrastructure, in many, if not all cases, is another barrier that prevents businesses from adopting blockchain. Blockchain offers a better way to store and manage data which leads to a redundant set of legacy infrastructure that is no longer required in most cases. Writing off invested systems is a not a business decision organisations are willing to take.
3. The link between the physical product and digital data stored on a blockchain is often challenging. Blockchain only maintains the integrity of data and fraud can still be committed by switching tags on products. To maintain the authenticity of products, it is mandatory to devise countermeasures that would mitigate risks of

changing the identifier label from a product and also prevent bad actors in the supply chain from replacing products inside boxes.

4. There is an obvious need to obfuscate transactions to avoid relating any sensitive information to competitors. In public and permissionless blockchains, it is hard to keep privacy merely because information is open to everyone for access. Hashing the contents of a transaction is not the best solution in cases where the number of inputs is limited.
5. Convincing participants and partners to share data is another challenge companies face while implementation. Blockchain experts suggest balancing between the amount and data that is shared and the amount of privacy required to run a business successfully.

Chapter 8. Discussion

This research has shown how blockchain technology can be leveraged to bring transparency regarding supply chain practices and end-to-end traceability of assets in supply chains. It describes a consortium based solution for two or more organisations, in the form of Hyperledger Fabric implementation which offers a single source of truth to all the participants in a business network. The research also demonstrated why it is relevant to use blockchain technologies in supply chains and the benefits associated with it. The use of Hyperledger Fabric is favoured as it provides scalability necessary for enterprise solutions which cannot be handled by permissionless blockchains at present. In addition, Fabric offers confidentially to supply chain participants, and sensitive data is not available publicly.

The use of blockchain requires expertise along with careful planning. In many cases, existing technologies offer a perfect and cheaper centralised solution, which cannot be discarded. The use of blockchain should be limited to cases where there is a clear need for a single version of truth among participants. Pilot programs are the best way to test out traceability after which certifications can be created to verify product traits. These certifications then prove authenticity based on the data stored on blockchain ledger, and the data is immutable and always kept on the ledger.

Permissionless blockchains offer many benefits yet fail to offer scalability and confidentiality required by organisations to achieve end-to-end traceability of products. Transactions in a permissionless network can be hashed for some privacy, but in most cases, it is unfeasible to use permissionless blockchain in supply chains as there is a clear need to obfuscate the transactions for more confidentiality and privacy. For example, a pharmaceutical company is going to be hesitant in publishing all information about a medicine product on blockchain as their competitors can see how many medicines the company is making, thus resulting in the company losing its competitive advantage. Businesses in order to stay competitive need to keep specific details private such as the name of their suppliers and the exclusive prices they pay for raw materials, which are the basis of their competitive advantages, and therefore the author has identified permissioned blockchain system to be a feasible solution for supply chain management.

8.1 Are permissionless blockchains disruptive?

After talking to experts, one is lead to believe and agree that permissionless blockchains are somewhat disruptive than permissioned networks. Permissionless blockchains such Ethereum span across thousands of nodes and allows anyone to verify transactions for free and without requiring any permissions to join the network. Transactions and smart contract consume a small fee in the form of gas paid by the end-user on the network. Permissionless network offers equal rights to every participant which is not the case with centralised institutions and permissioned blockchain networks. The benefit of building applications on Ethereum blockchain is that no additional cost is involved in setting up a network and also the added cost of using a certificate authority is eliminated as participants are anonymous an are not needed to be identified. Auditors do not need exclusive access for getting auditing information as it is available publicly on a permissionless network and participants can refer auditors to their transactions. Permissionless blockchains are also highly decentralised as compared to a small number of peers that exist in permissioned networks.

As revolutionary as this sounds, the proof-of-work consensus algorithm used in permissionless blockchains is unsustainable in the business context. The energy consumption of these networks is not feasible with the transactional demands of enterprises. Until there are permissionless solutions with better scalability and sustainability, permissioned networks are better suited to the needs of enterprises. Moreover, public access to supply chain information leaves no confidentiality that is necessarily required for conducting business.

8.2 Solving global Problems

It is not likely, at least in the near term future, that blockchain will solve any global problems of counterfeits. Let's take the example of counterfeit medicine. To effectively solve the problem of fake drugs, we need a global blockchain registry for every medicine product being manufactured around the world. It means that every company and their supply chain partners need to be convinced to use blockchain and risk their data being publicly available to everyone, which is a mammoth task to accomplish. Also, in the words of blockchain expert **E1**, "*It would be a bit far-fetched to say that blockchain solves global problems of drug counterfeiting*". Blockchain is a step in the right direction as it adds more visibility to supply chain processes and provides with a digital audit trail that is tamper-proof.

Manufacturers who use illegal subcontracting particularly in case of the clothing industry would be inclined to avoid the use of blockchain technology, as it would implicate them of wrongdoing with data on blockchain to back those claims. Companies who mean to do good would be delighted to use the technology for better audit trails and adding more visibility in supply chains with a trusted way to store verifiable information.

8.3 Clothing Industry

In the clothing industry, it is clear that companies have considerable power influence over other stakeholders and without transparency regulations, it is hard to convince them to publish supply chain information on the blockchain despite having consumer demand and pressure from NGO's to release supply chain information. Companies make use of manufactures that use sub-contracting especially from developing countries which is the source of human rights violation. The practices of these subcontractors are questionable, to say the least as there have been incidents of human rights violations exposed by SOMO. Companies who do not mean good and who are interested in covering their tracks would be less interested in using blockchain technology as it would lead a digital trail back to their wrongdoings. Consumer pressure alone isn't enough to force multinational clothing companies into releasing their supply chain information. SOMO along with 80 other civil society organisations has called upon the European Commission in an open letter [7], to develop a smart mix of regulations that would force companies to carry their due-diligence on working conditions and rights violation of workers.

In light of this information, it is impossible to define a traceable clothing product concerning the provenance of its raw materials, and accurate details of manufacturing. For a blockchain based traceability system to work in the clothing supply chain, it is crucial to identify all details about the lifecycle of clothes, which is not the intention of many big brands. It remains to be seen whether added pressure from regulators and NGOs would lead to the transparency of manufacturing processes in the clothing chains, which presents an opportunity for brands to use Blockchain for sharing information with regulators and customers in a trustworthy manner.

8.4 Blockchain & Farmers

Farmers require help farmers in the adoption process of blockchain technology, where significant efforts are required in educating the farmers regarding the correct use of technology. Having a mediator service provider to register a farmer's sale on blockchain presents us with a problem of trusting the mediator acting on farmer's behalf. For a fair blockchain system, small-scale producers should be included in the system directly. Farmers also need to understand the role of a private key and identify on the blockchain, and additionally how to secure these to prove their ownership. It is also possible that in many developing countries, farmers or their cooperatives do not have access to an internet connection. In such places, blockchain will not work without network connectivity.

8.5 Building Consumer Trust

Various extended models of TPB have shown the significance of consumer trust in a brand which also influences buying decision to some extent. Blockchain offers a way to build consumer trust by reducing a consumer's perceived risk regarding safety, quality, compliance and authenticity. By having an application for consumers as the means to verify traceability information, consumers have perceived control over buying genuine products. Availability of trustworthy information on blockchain lets consumers verify Fair Trade products before making a purchase. People who have a positive attitude towards Fair Trade and organic produce are likely to indulge in the verification of products.

Consumers should also be made aware of the importance of having tamper-proof data on the blockchain and why a consumer can trust it. Besides, traceability apps can also show benefits of Fair Trade product which can provide a great deal of accurate & current information to consumers that a label cannot. This also spreads awareness regarding Fair Trade, sustainable practices and social responsibility of brands as well as offers a way for brands to distinguish themselves in the eyes of a consumer.

8.6 Limitations

The first limitation is due to the scarcity of experts available in the field of blockchain technology. Due to the lack and unavailability of experts with considerable experience pertinent to the use of technology in entire supply chains, only four blockchain experts were interviewed during the data collection phase of this research. Efforts to consult additional experts did not result in a fruitful outcome. This limits the validity of research as it would have been ideal to include more participants; however; experts interviewed possess high knowledge from their experience of working with blockchain systems covering entire supply chains.

The quality of data collected from a small number of experts can, however, be considered high due to the following reasons. All experts have been directly involved in projects blockchain technology covering entire supply chain. All four experts also have at least two years of experience with blockchain technology relating to supply chain management. Two of them also consulted with the government on the use of blockchain technology which makes their knowledge from experience extremely valuable. To enhance the validity and reliability of this research primary data is also supported by secondary sources in the industry. The results of similar research in the future could differ due to the rapid developments that happen in the field of Blockchain.

Second, no practical validation was provided due to the limited timeframe of six months spent on this research and limited knowledge of researcher in implementing Blockchain solutions. Besides, the cost of such implementations is high and cannot be afforded by the researcher; therefore a theoretical system is proposed, and functional validation is suggested for future works.

8.7 Future work

The information provided in this research allows for an understanding of the permissioned blockchain technology which can be used in future to create experiments in the supply chains using the technology in a production environment.

Besides, much of the research done in the field of blockchain is theoretical and therefore for business students, it is suggested to find quantifiable benefits of using blockchain technology in a particular industry that would concretely demonstrate its advantages in numbers. This sounds easier than it is as you might need to find a way to find concrete evidence from successful blockchain implementations for comparison. However, with increased focused and research on the technology and a rise in the number of proof of concepts being successfully implemented, the technology is bound to enter production in the near term future. Moreover, as it happens, it would open up opportunities to locate hard evidence of supply chain benefits. Furthermore, this research provides a foundation for testing out benefits in practices by creating a fully functioning proof of concept.

No information is presented on the safety and storage of private keys which should be looked at for future research. Every participant uses private keys for authentication in a blockchain system instead of a traditional username and password approach. Passwords are easy to remember; however, it is tough to memorise a 32-bit private key, and we also need to store it somewhere safe. This presents us with usability and security challenges, which ought to be looked at for future works.

Finally, for computer science students, this research recommends looking into the use of Zero-knowledge proofs for enhanced privacy perhaps even on public blockchains. Hashed transactions are not the perfect solution as in cases where the number of inputs is limited; it can be easily deduced which input generates a particular hash that matches the hash in the transactions leading to no confidentiality. The use of Zero knowledge is also discouraged as it creates a significant overhead concerning computational processing; however, it could bring greater confidentiality and privacy to permissionless networks potentially making them disruptive. Furthermore, future researchers can study permissionless blockchains to induce scalability which is another area of high interest in computer science at present.

8.8 Recommendation

This paper has presented its readers with the viewpoint of researchers as well as Industry experts on the use of a nascent technology in supply chains. It is worth noting there is no one solution or one framework that fits all supply chain scenarios. The use of Blockchain opens up new business models and opportunities as presented earlier in this research; however, it is important to recognise the fact blockchain does not necessarily make supply chains safe. The technology allows us to collect information from various points in the supply chains but additional measures are required to maintain the accuracy of information.

Using Blockchain Technology in supply chains is a step in the direction for gaining consumers trust as it offers them with means to control their buying behaviour in a way that is beneficial to the consumer. The author recommends experimentation with blockchain technology against business goals, which will ultimately show whether or not blockchain brings benefits to the supply chain in focus. Technologies such as Ethereum and Hyperledger offer a way to conduct proof of concepts based on Blockchain technology. A model of permissioned blockchain network showcasing Banana traceability is shown as an example based on Hyperledger Fabric. Blockchain offers a way to secure validated information permanently from all points in supply chain and share it with every participant in real-time; however, it remains to be seen whether the technology will penetrate our consumer supply chains to have an impact on our society.

Appendix

Appendix 1:

Example of contact made with Zhijie for interviewing.

"Good Morning Zhijie,

I am a Masters ICT in Business student at Leiden University. For my master's thesis, I am exploring the use of Blockchain in supply chains for transparency and traceability of products. I am also looking to interview an expert in order to collect data for my research.
Would you please answer some of my questions in person or over a Skype call?

I would greatly appreciate your help.

Kinds Regards,
Mandeep"

Appendix 2:

Comparative analysis of data collected from Blockchain experts.

Theme	Expert - E1	Expert - E2	Expert - E3	Expert - E4
Is blockchain effective for product traceability	Blockchain is very good in making a digital trail of goods that move in real life, as long as the goods can be uniquely identified. It adds visibility to supply chains.	Yes, this is one the use cases of blockchain technology and traceability can be effectively achieved with permissioned blockchain technology.	Traceability can also be achieved without blockchain. Blockchain is not necessarily required in every situation so careful planning is recommended. We Successfully tracked coconuts and coffee beans using blockchain.	Extremely effective in tracking products and fraudulent Behaviour. We successfully conducted a POC for detecting counterfeit medicines.
Cost effectiveness	Ethereum is not cost effective presently for enterprise use. With the use of Hyperledger, you bear a lot of classic IT infrastructure cost.	Permissioned networks are feasible. RFID equipment is costly.	Ethereum is not cost effective at the moment.	The technology is improving and people are working to make blockchains more cost feasible.
Problems in supply chains	- Companies are not willing to share data - Food supply chain sustainability - Everyone maintains their own information centrally and in silos.	- Linking blockchain with the physical world to get reliable data. - QR codes can be copied and Malicious actors switch codes on products. - Every product is different and needs different way of linking	- Farmers are paid below poverty lines. - There is a need for sustainability - Food Supply chains inefficient which has great economic, environmental and social consequences.	- Organisations focus more on the technology rather than focusing on the processes. - Proving authenticity - Business will need to deal with multiple blockchains. Eg one for finance. One for order management.
Tackling human rights violations with blockchain	- Very cost intensive. - Blockchain only adds visibility to supply chain assets and integrity to data. - It would be far-fetched to say it solves global problems. - Blockchain does not fully eradicate the problems	It is feasible to do so and dependent on how much data companies are willing to share to effective create audits.	**DID NOT DISCUSS**	With the help of independent inspections agencies it possible to create random audits. Like it is happening in the case of diamonds with Everledger, where information regards the mining of diamonds is stored on blockchain and auditors are able to get real-time access
Barriers to entry/ Challenges in adoption of blockchain technology	- Confidentiality required - Illegitimate reasons - Legitimate reasons - Cost effectiveness - No quantifiable proof of benefits - Lack of knowledge and resources - Legacy Infrastructure	- Unwillingness to share data from participants. - Privacy vs transparency - Linking digital with the physical world. - Avoiding collusion from more than 1/3rd of the participants in Hyperledger Fabric.	- Cost impact - Creating shared value and incentives for every participant especially farmers.	- Scalability of blockchains. - Not sure about the legality of smart contracts. (you will need to consult a lawyer).

Theme	Expert - E1	Expert - E2	Expert - E3	Expert - E4
Benefits of using Blockchain in supply chain management	- Enhanced supply chain visibility - Cheaper Audit trails - Fraud detection - Digitalise bill of lading at ports - Increased efficiency	- Traceability of goods and products - Certifiable claims. - Share information efficiently - Remove paper processing but it should not be the the primary use case as digitalisation can remove paperwork.	- Enhances transparency in supply chains to counteract food Bourne diseases. - Offers a way to prove fair trade. - Supply chain efficiencies - Supply chain governance and compliance to regulations.	- Tamper-proof data - Permissioned networks have a lot less power consumption than bitcoin network. - Efficient Auditing - Informations for customs and tax all in one place
Recommenda tion	- Validate Business concepts with Hyperledger or Ethereum. - Make trade off and chose the best platform for production. - Prefers open infrastructure.	- Permissioned consortium based blockchain solution with Hyperledger. - RFID over QR codes.	Open source and open solutions. FairFood is interested in evaluating various available solutions for traceability of various food products.	- Throughput and latency are key design decisions. - Consortium with a flexibility of switching blockchain service providers. - Permissioned networks have huge advantages - DPOS consensus.

End notes

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