Tracing Blockchain Value

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Understanding The Case Of Blockchain In Supply Chain Traceability

by

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Preface

This thesis finalizes my life as a student. It also represent the paths I've taken to get here, combining both Electrical Engineering and Management. It combines in depth knowledge of complex technology, business acumen, and the awareness of intangible factors influencing technology adoption. To me, it is the fusion of these worlds that represent the intellectual challenges at Delft University of Technology.

I would to thank some people for supporting me in getting to this point. First I would like to extend many thanks to Drew for trusting me with this project and making considerable efforts in helping me succeed. Our meetings, early morning Fridays ever since November, had the perfect balance of casual conversation and actually getting stuff done. Thanks also to Tripti for these sessions, and the rest of Heineken and the Procurement Enablement team for welcoming me and showing me around the office, even though this stay was of short duration.

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As this is the conclusion of my chapter at the TU Delft, I also would like to take the opportunity to appreciate everyone who has made it feel like home for seven years. First of all, my friends at Club Volt and my roommates, both at the Balpol and OD122. Lastly, I like to thank my friends at the ETV, especially my 145th Board, for accepting an Management student in your midst.

I would like to thank my girlfriend Johanna for her endless support. We got together when this project started and you have been there for me all the way through. You have shared your room with me in this working-from-home era and you were there when I went through the inevitable ups and downs of the graduation process. I assure you I will return the favor when you will go through it.

And finally I would like to thank my family, especially my parents. Whatever I chose to do, I always felt your full support. Whether it was studying engineering, taking a year off or switching to management, I could always count on you for advice or help. You created every condition necessary for me to succeed and without you, I would not be here. For that, you will forever have my respect, thanks and love.

Now I sign of thanking everyone again, including those I missed, and I wish you happy reading. I am excited to see what the future will bring.

D.J. Buist
Delft, September 2020

Executive Summary

Modern supply chain and procurement departments are faced with a lot of challenges. Supply chains have become global, resulting in complex networks. With access to more information customers have access and have become more demanding on issues such as quality or sustainability. This has led to an increased interest among different companies in improving their traceability capabilities. As this requires companies to collect data across their entire supply chain, new technologies are being explored to make this change happen. One of these new technologies is blockchain. It rose to fame in the financial industry, but it is certainly a topic of current interest in supply chain management as well. Blockchain is a way to store and share data in an immutable ledger by decentralizing consensus, without a central record-keeping authority

This thesis is about the use of blockchain in supply chain traceability use cases and the comparison between blockchain-enabled traceability systems and traditional, centralized systems. Through literature review and a case study, which involved expert interviews and a survey, the main research questions from this thesis was answered: **Which food supply chain traceability use cases are suitable for the application of blockchain-enabled systems**?

In order to answer the main question, the following sub-questions were addressed:

- What drives the demand for traceability in food supply chains?
- How do traceability systems based on blockchain compare to centralized systems?
- Which criteria make a use case suitable for blockchain technology?
- Which challenges exist for successful traceability system implementation?

Based on the literature review, many studies suggests that food safety and quality are the primary drivers for an increased attention to traceability. However these suggestions were not found in this study. The needs for traceability at Heineken are mainly related to consumer demands and operational efficiency. Sustainable or local sourcing and decreasing costs related to mismatched information between Heineken and its suppliers or customers are dominant elements in the case study. In these situations, trust in data integrity is critical, which leads to certain managers looking to increase their traceability capabilities.

Next, blockchain traceability systems were compared against traditional, centralized systems to answer research the second research question. Blockchain systems outperform centralized systems on Transparency and Integrity, Trust and Data Quality. Although technologically the two implementations are distinct, it was found that in its usage the two are not that different. It was never mentioned that blockchain systems could fulfill use cases that traditional systems could not handle with regards to supply chain traceability.

This study found that blockchain use cases in supply chains should adhere to the following criteria:

- The network is decentralized, meaning it involves multi-tier suppliers and/or distributors.
- A high degree of proof of integrity is required.
- There is a desire to obtain a single view / version of the state of the system.
- Data sovereignty is essential.

These criteria were found to be most applicable to Product Provenance, Sustainable Sourcing or Product Recall use cases.

This research focused on understanding the differences between centralized and blockchain-based traceability systems. It has shown that blockchain can provide value to modern supply chains, and that in its usage, it is not radically different from centralized systems. The research presents criteria to decision makers, which provide support in judging the need for blockchain in their applications and reviews the areas where these needs could be and which challenges this presents.

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1 Introduction

Modern supply chain management is faced on one end by increasing customer quality demands and on the other end by increasingly complex supply and distribution networks [1]. Supply chains have become even more international and manufacturers often make use of a plethora of different suppliers and production sites. This means an incident at a supplier in Brazil can have big consequences for a manufacturer in Germany. Even in a world that is more connected than ever, the COVID-19 crisis has shown how fragile some supply chains are and how hard it can be to collect basic information from suppliers in high stress environments. Supply chain visibility and traceability are therefore high on the agenda. The industry is also said to be undergoing a digital transformation, called Industry 4.0 [2]. This fourth revolution of industry will be characterized by an exponential increase of deployed sensors, gathered data and use of advanced analytics.

These developments in itself have a lot of potential to add value to the supply chain operations. With these developments gathering, storing and sharing information becomes more important. This has been an issue in supply chain management for decades. Information cooperation is important in improving efficiency, however currently the access to information and creating value in a secure way is limited [3].

Blockchain has been proposed as a tool to eliminate the problem of information asymmetry in supply chain networks and increase efficiency, reliability and transparency [4]. In 2008 Satoshi Nakamoto released the whitepaper for Bitcoin, a peer-to-peer electronic cash system [5]. The coin was introduced to enable people to make payments to anyone around the world without the need for a central authority. The technological principle behind Bitcoin has over time created more buzz and excitement. Blockchain was first picked up by the financial industry, where it was met with as much fear of displacement as curiosity to new implementations.

Since many more industries have been looking towards blockchain as a potential solution for their specific business issues. One of the sectors is supply chain management. The technology itself is however still surrounded by a lot of uncertainty. Companies are trying to cut through the hype and determine when and how blockchain can deliver true business value to their operations. The development of different blockchain platforms and the fairly complex technological principles do not make this task any easier.

One of these companies is the HEINEKEN Company. This research is a case study in cooperation with them. Heineken is the second largest beer brewer in the world and has already been involved with some blockchain pilots, but they are still unsure about its value and its unique value. Supply chain traceability has been the application area, as Heineken is also impacted by demanding consumers and complex supply chains.

New research can benefit from a huge amount of work already done by academia and industry when blockchain was at the top of the hype cycle. A lot of material is available on the theoretical implications of the technology on supply chain. Also, the first real-world pilots have been performed, with varying results and documentation. But still, there is no agreed view on blockchain value, platform suitability and implementation rates.

1.1. Problem Statement and Research Questions

Technology procurement managers, like at Heineken Global Procurement (which manages procurement activities for Heineken International), are seeing a lot of different blockchain pilots being deployed around them. Technology solution providers have developed many commercial offerings based on blockchain and also internally technology managers feel pressure to adopt this new technology. There is a lot of hype, but few production ready proof-of-concepts. This creates problems for the people in charge of deciding on the adoption of new technologies, like at Heineken Global Procurement as they are the ones being faced with this uncertainty. They want to prevent themselves joining a technology based on hype, and want to make their decisions based on actual business value instead. Therefore, the problem statement is defined as follows:

> *Problem Statement: "There is a lot of uncertainty surrounding blockchain technology and its value, hindering technology managers to select promising projects"*

Blockchain is a broad technology, with many different applications for it. As the work of this research is being done mainly for Heineken Global Procurement, the scope of this report will only be on supply chain related applications, even if other applications could be of interest to Heineken. To further narrow this scope, from the discussions preceding this research the feeling was that supply chain traceability applications are receiving the most attention when combined with blockchain, so this will be the primary application under investigation. Therefore the main research question is defined as:

> **Which food supply chain traceability use cases are suitable for the application of blockchain-enabled systems?**

This has been the motivation to start the work of this thesis. The goal of this project is to (1) deliver a overview of the current state of blockchain technology, (2) outline what sets it apart from other technologies, (3) and indicate when business value could be created with blockchain technology

First, considering the scope of this research, it needs to be determined what the needs are for traceability systems in supply chains. The needs for traceability can differ between products, geographical location or organizational context. When assessing the unique value of blockchain to traceability systems, knowing why these projects are pursued at all, is a good first step. This means the first research question that needs answering is the following:

> **RQ1: What drives the demand for traceability in food supply chains?**

Next, it should be factored in how solutions can meet those needs. Blockchain traceability systems are often compared to more traditional systems, based on centralized databases. The vagueness around blockchain has hindered decision makers to understand the differences with existing solutions. This results in the second research question, with related subquestions:

> **RQ2: How do traceability systems based on blockchain compare to centralized systems?**
>
> *RQ2.1: Which criteria are important for comparing traceability systems?*
>
> *RQ2.2: What features are unique to blockchain?*

Third, not only the difference between implementations, but also the application area is expected to have an effect on the value of either solution. This means the third research questions is defined as:

> **RQ3: Which criteria make a use case in the food supply chain suitable for blockchain technology?**

It is known that technology implementation is influenced by a lot of different variables and that success of adoption is not only determined by the technology under investigation. Also in this use can be made of existing literature. Therefore a final research question that needs to be answered is related to this:

> **RQ4: What challenges exist for successful traceability system implementation in food supply chains?**

Link to the Management of Technology Programme

The Management of Technology (MoT) Programme itself states that it intends its graduates to learn to explore and understand how firms can use technology to design and develop products and services that contribute to improving outcomes, such as customer satisfaction, corporate productivity, profitability and competitiveness.

A typical MoT thesis is considered to include the following things:

- The work reports on a scientific study in a technological context (e.g. technology and strategy, managing knowledge processes, research and product development management, innovation processes, entrepreneurship).
- The work shows an understanding of technology as a corporate resource or is done from a corporate perspective
- Students use scientific methods and techniques to analyze a problem as put forward in the MoT curriculum.

These certainly apply to this research. This study takes a technology, in this case blockchain, and puts it in a corporate perspective, namely that of supply chain processes in the HEINEKEN Company. Understanding how this technology can be used in an effective way as a corporate resource is at the heart of this research. By using certain scientific methods, like the cases study, interviews and a survey the problem is tackled.

1.2. Methodology

The study will be in the form of a case study. Case studies are empirical inquiries that investigate a contemporary phenomenon within a real-life context where the boundaries between phenomenon and context are not clearly evident and in which multiple sources of evidence are used [6]. This study will perform such a case study to explore the role of traceability systems and the applicability of blockchain technology in the context of the case study company. This gives the opportunity to study how the issues are regarded in practice.

The data collection will be done through literature review, expert interviews and a small survey. The steps taken in this research are represented in the research flow diagram in Figure 1.1. From the Internal Interviews, knowledge will be gathered about the needs for supply chain traceability in the case company and exploratory investigation of barriers to implementation.

The results from these interviews are also used during the External Interviews, and the use cases presented during the Internal Interviews serve as input for use case validation in the second part of the survey. From the External Interviews, unique blockchain features are distilled that justify the use of blockchain for supply chain use cases. These features are fed into the second part of the survey to test how relevant those features are to the various proposed use cases. Results from the first part of the survey are used to validate the results from the external interviews.

1.3. Structure

In Chapter 2, first an introduction of blockchain technology and its principles is given. The aim of this chapter is to create an equal understanding of blockchain with all readers and display that blockchain technology is an overarching name for many different implementations, each with its own specific characteristics. In Chapter 3, a literature review of contemporary supply chain issues is presented, before connecting it to the knowledge base on blockchain in supply chain, providing input to RQ 2, 3, 4 and the main research question. Chapter 4 builds on the concept of traceability introduced in Chapter 3 and specifies this for the food supply chain, the main sector of this case study, building the knowledge base for RQ 1, 2 and 4. The research protocol is presented in Chapter 6. Chapter 7 presents the empirical findings of the research, which are discussed and confronted against the literature in Chapter 8 before Chapter 9 concludes this thesis. Additional materials can be found in the Appendices.

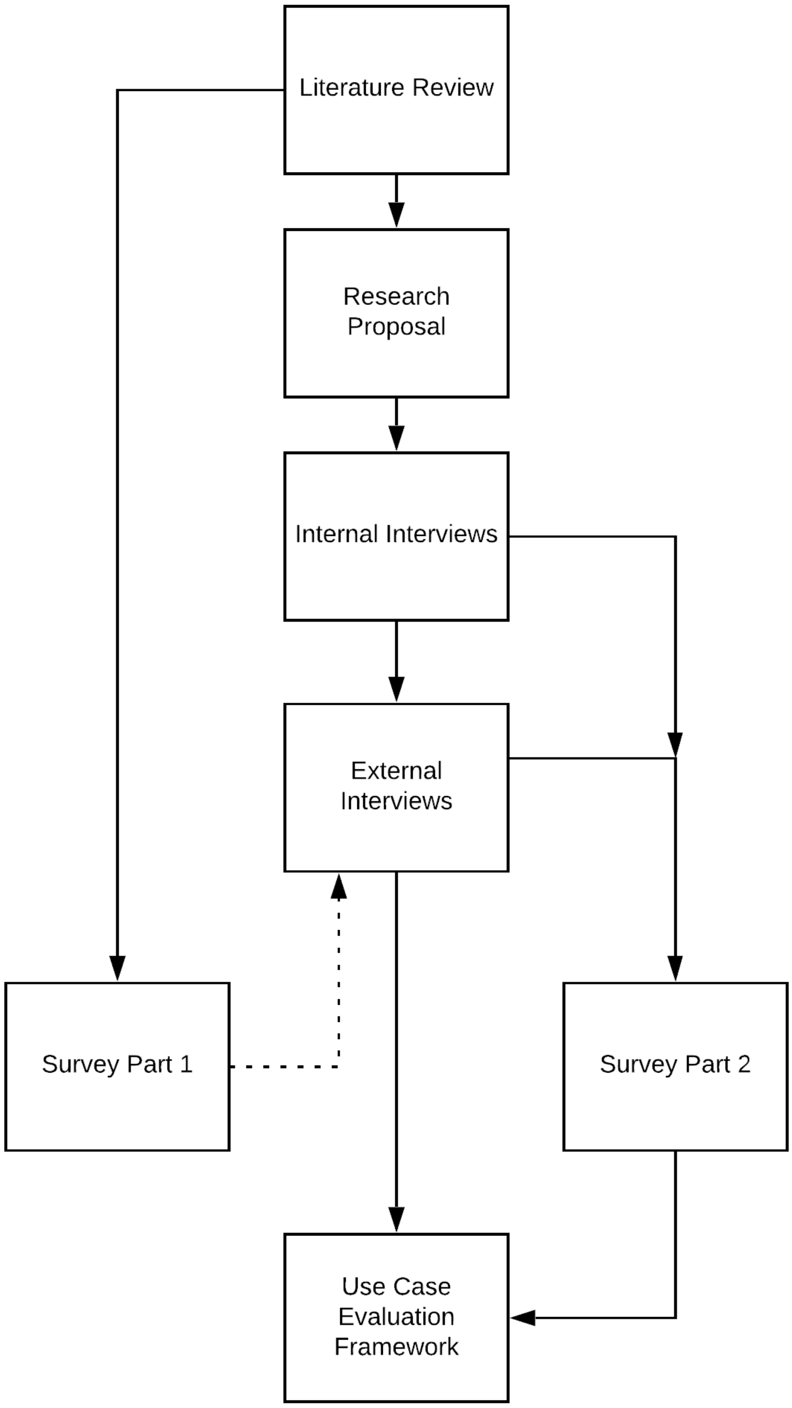

Figure 1.1: Research Flow Diagram

2 Blockchain

This chapter is a review of blockchain technology. First the basic operations and characteristics will be explained, and after that an overview will be given of some well-known blockchain platforms. Furthermore, attention will be given to the cryptographic aspects of blockchain and its vulnerabilities related to security. This chapter supports the reader of this report to obtain an adequate understanding of blockchain technology and terminology for the remainder of this report.

2.1. Principles

Blockchain is a technology that enables the storing and sharing of data. It is a fully distributed ledger containing transactions previously made on that blockchain. The rise to fame of blockchain technology came in 2008 with the creation of the cryptocurrency Bitcoin. This currency got a lot of attention for the fact that it was unregulated. Trust in the system was not established by a governing third party, but rather by relying on cryptography.

Since the introduction of Bitcoin, a lot of blockchain varieties have been developed, with some common characteristics. The defining properties for blockchain technology according to Aste et al. are the decentralisation of consensus, transparency, security and immutability [7]:

- **Decentralisation of consensus**: Consensus is the method for validating the chronological order at which requests, transactions, and information have been executed, modified or created [7]. The chained architecture of blockchain makes it important that the order of transactions is correct as this defines ownership of certain assets. The decentralised part means that there is no trusted third party or central authority to approve transactions and rules. This means that there is no single point of trust and also no single point of failure. There are different ways of establishing consensus.

- **Transparency**: A requirement for public verifiability is the transparency of data and the process of updating the ledger state [8]. This does not necessarily mean that everyone on the blockchain has the same view. Different blockchain architectures allow for selection of the rights of participants. The initial Bitcoin blockchain is fully public and permissionless, so it does give full transparency to all participants in the network.

- **Security and Immutability**: Blockchain is a shared, tamper-proof replicated ledger where records are irreversible thanks to one-way cryptographic hash functions and community consensus [7]. Although security is relative, it is said that blockchain is relatively secure because transactions can only happen if users possess the required private key. These private keys act as a digital signature for the transactions.

  Blockchain immutability means that data that has been stored on the ledger cannot be changed after the fact without approval of the entire network. The strength of this immutability also depends on the architecture of the system [9]. There are several known security challenges, both from a technical and governance perspective. These will be addressed in following sections.

It also categorizes two important, but non-fundamental properties of blockchain: data automation and data storage.

- **Automation and Smart Contracts**: The term smart contract was already coined in 1994 by cryptographer Nick Szabo, but radical improvements in IT and now especially with blockchain have reinvigorated its viability. Smart contracts represent programs that automatically validate and execute conditions that have to be realised in order to complete a transaction [10]. They can contain the same elements as in conventional contracts but they are distinct in three ways according to Swan [11]:
  - Autonomy: This means that after launching the contract on the blockchain, it is no longer necessary to interact with the contract.
  - Self-Sufficiency: They have the ability to marshal resources themselves. They can raise funds by providing services, or spend them on needed resources.
  - Decentralization: They do not exist on a single server, but in a distributed network.
- **Data Storage Capacity**: The storage space available on blockchain networks can be used for the storage and exchange of arbitrary data structures. Alternatively, the storage of additional data can occur "off-chain" via a private cloud on the client's infrastructure or on public (P2P or third-party) storage.

2.2. Digital Signatures

Digital signatures are analogous to handwritten signatures in that they are added by the other party to indicate that they approve of the message. They are however distinct in the fact that they are not as easy to copy as a handwritten signature.

One method of creating digital signatures is using asymmetric cyphering or public key encryption. This system has many advantages over symmetric systems; the main one is that they do not require two communicating parties to know each other before encrypted communication can take place [12]. In addition, the use of digital signatures allows users to sign digital data such as electronic orders or money transfers. Therefore, public key ciphering is essential for blockchain systems [12]. There are several public key encryption systems, the most popular being RSA.

In public key encryption, use is made of a public key (pk) and a private key, also known as secret key (sk). Messages are ciphered using the public key (under a certain algorithm) before being sent. Only by then using the private key, the message can be deciphered again. Therefore anyone can send encrypted messages to someone, using the public key, but only the user, using his secret key, can decrypt the message. The public and secret key are linked mathematically so that it is impossible to determine the secret key from knowing the public key, but not vice versa. Knowing the public key, the message and the signature does provide the possibility to verify authenticity.

$$Sign(Message, sk) = Signature \tag{2.1}$$

$$Verify(Message, Signature, pk) = True/False \tag{2.2}$$

To really understand how this works, the RSA algorithm is taken as an example. RSA was the world's first public key encryption algorithm and is still the most popular one. The strength of the algorithm is based on the difficulty of finding the prime factors of two large integers.

In the following, by means of an example, the operation of blockchain systems is explained by constructing the logic step by step. This example involves a ledger that stores transactions between participants. It can be described by using the analogy of 4 friends, recording their mutual transactions in a shared ledger. You have three friends called *Alice, Bob* and *Charlie*. Anyone can add lines to the ledger, for example *Alice* pays *Bob* 100 euros. To prevent people in *Bob's* position to add similar lines without *Alice's* approval, the blockchain uses digital signatures.

A demonstration of how this RSA algorithm works, is to consider the case that Alice wants to receive encrypted messages from anyone on the network. To do this she first picks two large secret prime numbers p and q. She then computes:

$$N_A = p_A * q_A \tag{2.3}$$

and a encryption exponent ϵ_A, such that

$$gcd(\epsilon_A, \phi(N_A)) = 1, \tag{2.4}$$

where gcd stands for the greatest common divisor and $\phi(N_A)$ is Euler's totient function of N_A. Because p and q are primes $\phi(N_A) = (p-1)(q-1)$. From these, d_A is calculated as:

$$d_A = \frac{1}{\epsilon_A} mod \phi(N_A) \tag{2.5}$$

is considered as the public part and (d_A, p_A, q_A) the secret part.

As $Alice$ sends the message m and the signature

$$s_A = m^{d_A} modN \tag{2.6}$$

Bob can check the authenticity of $Alice$ and the message by veryfying that

$$m = s_A^m odN \tag{2.7}$$

The verification that a signature is valid is done by considering the message, signature and public key. Theoretically it is possible to decipher the message as an outsider, but because generally use is made of 256 bit signatures, this job becomes technically infeasible, just by the sheer number of possible options ($= 2^{256}$). It does not prevent that the same message is copied multiple times to the ledger (as the content is still the same, so will be the signature). Therefore a unique ID associated to that transaction is also added to overcome this problem.

2.3. Consensus

To prevent a central authority from tampering with the ledger, blockchain is a so-called decentralized ledger. This means that all nodes in the network keep an up-to-date copy of the ledger. When a transaction is made, an update is sent to all other nodes in the network. This creates the challenge for "outsider" nodes of verifying that a transaction actually took place and that every node records the same message and in the same order. It is also important to check that an item has not already been spent in another transaction. This issue is called the double spend problem.

The main idea to solve this is that nodes will need to find a way to trust the ledger. Bitcoin achieved this first by relying on the amount of computational work put into it, meaning nodes would trust the version of the ledger which was the longest. This computational work is done by calculating cryptographic hash functions. By trusting the ledger with the largest amount of computational work, it becomes computationally infeasible to trump this ledger.

A hash function takes any string as input and outputs a string or "hash" of a fixed length. This length of the hash is 256 for the well-known hash function SHA256. By changing any part of the input string, the output hash changes completely in an unpredictable way. By using the SHA256 hash function it is totally infeasible to reverse from the hash to the input message. Again, theoretically it would be possible, but no one ever has been able to demonstrate this ability. Therefore, SHA256 is one of the most common cryptographic standards in digital security.

There are numerous examples of consensus mechanisms [13]. Tasca and Tessone [9] categorize the consensus mechanisms as having four subcomponents, influencing the design of a blockchain system interdependently. These are network topology, consensus immutability and failure tolerance, gossiping and agreement.

2.3.1. Network Topology

Network topology describes the type of interconnection between the nodes and the type of information flow between them for the purpose of transactions and/or validation. Three general network topologies are discussed by Tasca and Tessone.

Historically, system have been designed in a centralized way as this was more efficient, lowering configuration, maintenance and adjustment costs [9]. A centralized system does provide a single source of failure. Therefore, during recent years, decentralized systems are getting more attention. In a decentralized system, there is no single point of failure as the consensus decision is made across the network. A system can also be an intermediate hierarchical network, where some nodes of the network control flow and consensus, this is often the case in so-called consortium blockchains [9].

2.3.2. Immutability and Failure Tolerance

The failure tolerance of distributed systems should be defined with respect to three issues: faults (e.g. Byzantine faults), errors and failures. These failures are best described by the Byzantine General Problem, introduced by Lamport et al. in 1982 [14]. This problem involves the coordination of movement between several spatially separated armies. The generals of these armies have two options, either attack or retreat. To succeed, all generals need to do the same action. To coordinate, the generals have the possibility to send messages to the other generals. However, some of the messengers might fail in delivering the message or some of the generals might be traitors and send out false or corrupted messages.

The Byzantine Generals problem serves as an analogy to distributed computer systems, where the generals are network nodes and failing or corrupt nodes are referred to as Byzantine nodes. A Byzantine Fault Tolerant System (BFT) is a system which is able to operate even in the presence of these Byzantine nodes. Lamport et al. show that there is no solution for when $>\frac{1}{3}$ of the nodes are Byzantine nodes. For the remaining cases, there is the Practical Byzantine Fault Tolerance algorithm (PBFT). There are several ways to overcome this, using certain consensus algorithms. Some of the most common ones are discussed below:

Proof-of-Work

Proof-of-Work (PoW) was used by Satoshi Nakamoto to overcome the double spend problem for Bitcoin [5]. In Bitcoin every block is added with a special number, which makes sure the output hash function starts with 30 leading zeros. Because use is made of cryptographic hash functions, the only ”practical way” to find this hash is by trying out all possibilities until you find one that hashes the message and special number to start with the required amount of leading zeros. The probability that a hash starts with 30 leading zeros for example is $\frac{1}{2^{30}} \approx \frac{1}{1000000000}$. This means that to find the number, a computer has to try out a billion different possibilities until it finds the appropriate hash. A great deal of computation is involved in this, while in contrast the verification is relatively easy. One can just run the hash and verify that is starts with 30 zeros.

In the same way in which a transaction is only considered valid when it has a digital signature, a block is only considered valid when it contains a proof-of-work. To make sure there is a standard order to the blocks, a block has to contain the hash of the preceding block in its header. In this way, it is not possible to change the order of blocks, as hashes are unique to a block. This makes changes obvious as the block is pointing to the wrong previous block. In order to be able to do this, one would have to redo all the proof-of-work done for all preceding blocks, making it computationally infeasible. It is due to this property that this technology is called a blockchain and not only a ledger.

A blockchain allows anyone in the world to be a block creator. They will do the required work to find the suitable hash and deliver the proof-of-work. These machines are called miners. When a miner has found the suitable block, it transmits it back to all the nodes in the network. As a reward for doing the computational work, the miner can add a line to the ledger with a reward, which requires no signature.

From participant’s point of view, instead of listening to transactions being made, it waits for blocks created by miners to update their own copy of the ledger. A key principle here is that if a node receives two distinct versions of the same chain, it will choose the longest one as that one has required the most computational work. If two chains are equal, the node will wait until one chain gets updated with an extra block. As long as all participants agree to this principle, no longer does the system require trust in a central authority to verify the integrity of the system; instead it trust purely in computational work.

To validate this trust in computational work, the following example is proposed. *Alice* could try to fool *Bob* by sending a fraudulent block with a false transaction, without broadcasting it to the other nodes in the system. This could happen if *Alice* can make sure she finds a valid proof-of-work before all other miners in the system, which could technically happen. Still all the other miners will eventually be sending out their own version of the chain, making *Bob* unsure what the actual state of the ledger is. This is called a fork in the chain. As long as *Alice* is able to compute proof-of-work before the other miners, this could work. However, because of the way a blockchain works, it is usually impossible to continuously find PoW before all the other miners, therefore eventually the chain created by the other miners will be longer, leading to *Bob* rejecting the chain broadcasted by *Alice* and believing the longer chain of the other miners. The only way to be able to theoretically do this, a node needs to control at least 50% of the computational power in the network. Because forks can appear in the network, a newly added block to the chain is not 100% trustworthy. However, after several blocks have been appended to the chain, one can be increasingly confident that the chain is indeed valid.

Being a miner requires specialized hardware, i.e. machines with high computing power. These machines also require a lot of electricity to operate, making mining an expensive and resource intensive job, leading to a high energy footprint. Using Bitcoin as an example, being the biggest known blockchain network, its energy consumption was on par with those of medium-sized developed countries like Ireland [15]. It is up for debate if that is justifiable for the purpose it serves. This clear disadvantage of resource inefficiencies has led to the formation of mining pools [16], where the resources of different miners are combined to maximize the chance of successfully finding the required hash. This pooling however presents a threat to the integrity of the network because when a pool becomes powerful enough, (namely >50% of the total computing power), they can dictate which transactions are accepted or not. These are so-called 51% attacks.

Proof-of-Stake

Proof-of-Stake (PoS) does not depend on computational work to reach consensus, but rather uses a pseudo-random selection process to pick a so-called validator or prover based on either a node's value, coin-age or by random block selection. The most common selection criterion is the node's value. This process relates the probability that a certain node is chosen as prover to the share of assets the node has in the network.

In a Proof-of-Stake system, nodes wanting to participate in the creation of new blocks, now called forging instead of mining, have to commit a certain amount of coins to the network as their stake. A bigger stake means the node is more likely to be chosen. This assumes that nodes which have a vested interest in the well-being of the network will behave according to the rules. As a reward for their validation of a new block, forgers are paid a transaction fee rather than newly created coins. The PoS method avoids the cumbersome computational work of Proof-of-Work and is therefore much more resource efficient. A downside however is the risk that a network might be controlled by some wealthy nodes having a far bigger stake in the network than all other nodes. To combat this, the randomised block selection and coin-age based selection have been developed [9][17].

The randomised block selection method uses the validators which are selected based on a combination of the lowest hash value and the highest stake, since the size of the stakes are public; the likelihood of being the next validator can be estimated independently by the other nodes in the network. This method is used by NXT and BlackCoin.

Coin-age based selection selects validators on the basis of how long their tokens have been staked for. Coin-age is calculated by the number of days the coins have been staked multiplied by the number of coins at stake. Once a node has forged a block, their coin-age is reset to zero and they have to wait before forging a new block. This prevents domination of wealthy nodes. This method is used by Peercoin.

Proof-of-Stake also makes it harder to launch 51% attacks because of the monetary investments that need to be made before owning a share of the network. This investment will also increase with the size of the network, making it impractical and unappealing. Combining this with the energy efficiency, PoS has some clear advantages over PoW. However, it is also not without its security risks. The nothing-at-stake issue involves a validator working on several chains, which is possible as the cost of doing this is significantly lower than in PoW. This results in the blockchain never reaching a consensus and not being able to solve the double spend problem. A proposed solution to this is the Delegated Proof-of-Stake (DPoS), where only predetermined nodes can be selected as forgers of new blocks. This selection is done by the nodes with the stake in the network. They vote on the validator they trust to behave normally [17]. The bigger the stake of the voters, the greater their voting power. The DPoS system is used by platforms as BitShares, Capser by Ethereum and Tendermint.

Proof-of-Authority

Proof-of-Authority systems are somewhat similar to Delegated Proof-of-Stake systems. The key difference is that validators are not voted on and instead of a coin stake, the validators stake their own reputation. Validators are a limited list of pre-approved participants. This system is often used for private consortium blockchains as it is easier to find authorities which can be trusted to maintain the integrity of the system [9][18]. The fact that the number of validators does not need to grow as fast as the network, means that this solution is highly scalable, enabling high throughput in terms of transactions per second[18].

One of the challenges is to find and maintain trustworthy validators and establish a common standard across participants to agree on the list. Also, as this system foregoes the concept of total decentralization, it is regarded as an imperfect solution to existing problems in other consensus algorithms [18].

Proof-of-Capacity

The Proof-of-Capacity (PoC) method is similar to Proof-of-Work in that it returns to the power of relying on hashing for robust security. But rather than focusing on the number of computations (or CPU cycles), it requires miners to dedicate hard drive memory space. This has the advantage that memory is a lot cheaper, as it is commodity hardware, and more energy efficient than PoW [19]. It is used by Permacoin, SpaceMint and Burstcoin.

The process is divided in two parts, the so-called plotting of the hard drive and the actual mining. It can take several days or weeks to create a unique plot file, depending on the size of the hard drive. This is partly because PoC uses the Shabal hash function, which is significantly slower than SHA-256. Since Shabal hashes are hard to compute, they are pre-computed and stored on the hard drive.

During plotting, the machine creates nonces, which are created by repeated hashing of data. The more space is allocated to mining, the more nonces the machine can store. A nonce contains 8192 hashes, which are organized in pairs, known as scoops. Each scoop is a number between 0 and 4095.

In the second part, the mining process, a scoop number is calculated. Based on this result, you move to that scoop in each of the nonces and calculate a deadline. A deadline is the number of seconds that must elapse since the last block was forged before one is allowed to forge a new block. The lowest deadline for all nonces is chosen. If nobody else has forged a block within this time, one can forge a block and claim a block reward.

Figure 2.1: Representation of nonce [19]

The Proof-of-Capacity system is sometimes regarded as the eco-friendly alternative to PoW. There is no need for specialized equipment and using hard drives is much more energy efficient than application-specific-integrated-circuit (ASIC) based mining. It is the ultimate decentralized system as devices with are everywhere, including phones and basic computers. But even though the possibility of advanced mining farms is less likely than with Proof-of-Work, increased popularity of PoC could result in an explosion of the amount of resources devoted to this system [19].

Proof-of-Elapsed-Time The Proof-of-Elapsed-Time (PoET) consensus algorithm was developed by Intel for permissioned blockchain networks and is used for Hyperledger Sawtooth. It relies on a special CPU instruction set called Intel Software Guard Extenstions (SGX). SGX allows applications to run trusted code in a protected environment. This means no other programs can see or interfere with this code while it is executing, even when they have physical access to the device. Code that runs using SGX can produce a certificate that verifies that the code has been correctly initialized in a trusted environment.

PoET elects individual peers to execute requests at a given target rate. Individual peers sample an exponentially distributed random variable and wait for an amount of time dictated by the sample. The peer with the smallest sample wins the election [20].

PoET is much more efficient than PoW and is easily scalable. It provides an easy and efficient way of selecting a leader for consensus without complex staking mechanisms. Downsides of the technology lie with SGX. Some weaknesses have been shown [21] and the fact that it is provided by Intel, an external third party, could make it less desirable.

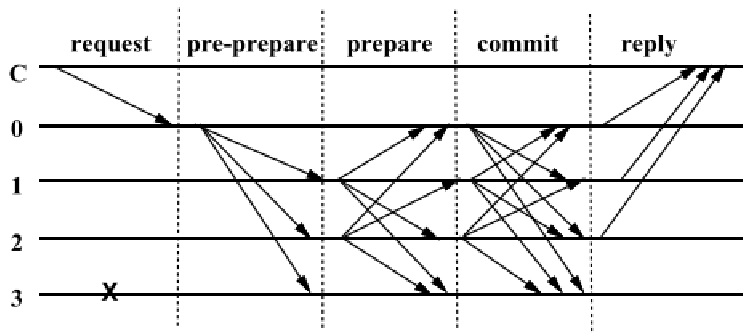

Figure 2.2: Schematic representation of messages send between 5 nodes in PBFT [22]

Proof-of-Burn

Proof-of-Burn algorithms are similar to PoW, but with reduced rates of energy consumption. The validation does not depend on doing the computational work, but rather in validators proving their commitment to the network by investing in the blockchain by ”burning” their coins. This burning means sending tokens to a publicly verifiable address, where they become inaccessible and useless. Similar to PoW, the miners will then be rewarded with block rewards and these rewards are expected to recover the initial investment made by the miners.

The advantages mentioned are the reduced power consumption, the creation of coin scarcity by burning coins, decentralization and no need for mining hardware. Although the claim for a more sustainable algorithm is disputed by some, as the burning requires to destroy coins which have been created by the energetically wasteful PoW algorithm, making it a wasteful activity in itself. It also has not been proven yet on a large scale and the throughput seems to be slower than PoW, so scalability is still a concern [**?**].

Practical Byzantine Fault Tolerance

Practical Byzantine Fault Tolerance (PBFT) was invented in 1999 by Castro and Liskov as a solution to the classic Byzantine General problem [22]. The PBFT can handle systems with up to 1/3 adversarial Byzantine nodes, or f Byzantine nodes in a network with $3f + 1$ nodes [22][23].

The main algorithm consists of three phases: pre-prepare, prepare and commit. It begins when the client node submits a request to the primary node. The primary node is responsible for advocating for the client request. In the pre-prepare phase, the primary nodes send out messages to all other nodes in the network. A node accepts a message as long as it is valid, which is determined by a sequence number and signatures.

When the message is accepted by a node, it sends out a prepare message to the other nodes. This prepare message needs to be accepted again by the other nodes. A node is prepared when it has seen the original request from the primary node, has pre-prepared and has seen $2f$ prepare messages, matching the pre-prepare message, so this makes a total of $2f + 1$ prepare messages. After nodes have prepared, they send out a commit message. If a node has received $f + 1$ commit messages, they carry out the client request and then send out the reply to the client node. The client node waits for $f + 1$ commit messages to allow for f faults. Figure 2.2 shows a representation of the communication in this algorithm with 1 client node C and 4 other nodes. In this example, node 0 serves as the primary node.

The algorithm has only ever been scaled to 20 replicas, having an significant increase in overhead with regards to the messages, given rise to concern about is scalability. [24]. It is being used by Hyperledger as one of the options for consensus.

Federated Byzantine Agreement Federated Byzantine Agreement (FBA) was introduced as a new version of the PFBT algorithm which was designed to take away the disadvantage of the increased centralization of PFBT introduced by having a system of pre-selected validators. It is also supposed to combat the limited scalability caused by the large communication overhead [21].

In Federated Byzantine Agreement, each node decides for themselves which node to trust. It is an open system, enabling a permissionless configuration. FBA received more attention as the Stellar

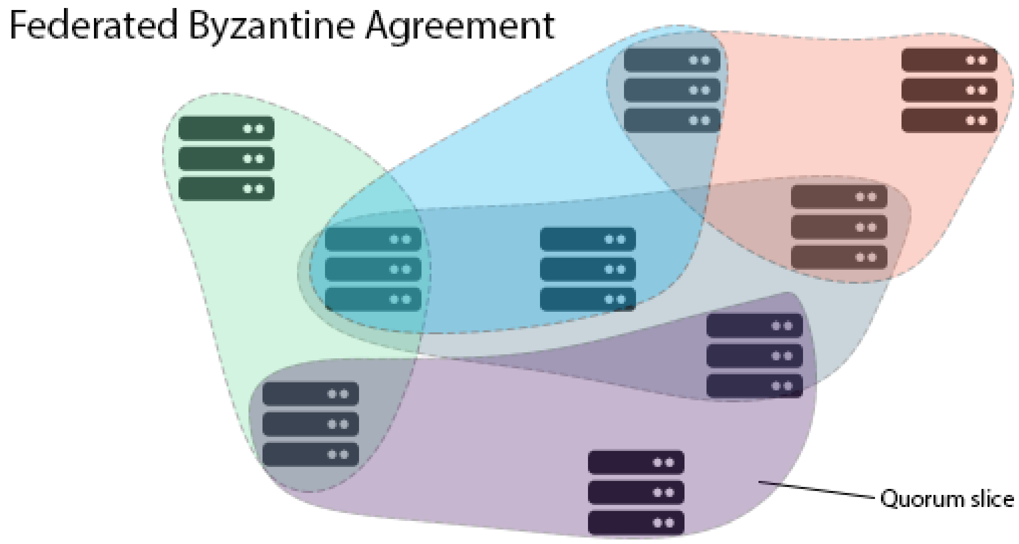

Figure 2.3: Federated Byzantine Agreement [26]

platform used a version of it as its consensus algorithm.

FBA introduces the concept of quorum slices. A quorum is a set of nodes sufficient to reach agreement. In FBA each node decides what other nodes to trust. This list of trusted validators creates a quorum slice. Nodes in a quorum slice influence the opinion of other nodes. [25]. A node can depend on numerous slices for information and this trust can be based on information from outside the system [21]. A good system consists of quorum slices that overlap, called quorum intersections. A system needs to have quorum intersection; otherwise disjoint quorums can arrive on different versions of the system state, see Figure 2.3.

The absence of a central authority, places the responsibility to achieve quorum intersections at the individual nodes.

In FBA, a node agrees to a statement if there exists at least one quorum slice which also agrees to that statement [27]. A v-blocking set is a set of nodes from each slice which can then eventually change the vote of the node if they all agree on the same value.

There are four Federated Voting phases: initial voting, acceptance, ratification and confirmation. During initial voting, nodes vote for the statement which they think is valid and that they assert that they will not vote for a contradictory statement. This vote can however still change if a v-blocking set agrees otherwise. This happens during the acceptance stage. If this is not the case, the statement is accepted by the node. During ratification, all members of a quorum vote to accept a statement. If they do, the statement is ratified by all nodes.

2.3.3. Gossiping

Gossiping is the protocol the system follows on how to route new messages through the system. A protocol is necessary as no central authority can autonomously govern communication between nodes. Two general protocols are discerned, local gossiping and global gossiping.

In local gossiping, nodes send out their new version of the ledger to their neighboring nodes. The local nodes then reach consensus on the new state, before sending out the new version to the entire network. This form of gossiping of is also called federated consensus and is used for instance by Ripple.

Global gossiping is the most common form and is used by Bitcoin and Ethereum. In this arrangement, a node has been assigned a certain fallback node upon entering the network. It sends its new state of the ledger to this fallback node, which keeps a list of all the peers in the network. These fallback nodes then broadcast the new state of the system.

2.3.4. Agreement

This section involves how nodes communicate and how they independently update their state of the ledger. Two important components of this process are latency and finality.

Latency Latency is defined within computer engineering as the delay before a transfer of data begins following an instruction for its transfer. Generally speaking, the two ways to do have communication in a distributed system are asynchronous and synchronous.

Synchronous systems intentionally delay the processing speed for some nodes in order to have all messages arrive within a certain known time interval. This delay does not account for latency outside of the network, but bounds it and discards all messages outside the upper latency limit.

Finality It is important to recognize that the various consensus algorithms have a a different way of establishing the final (most recent trustworthy) version of the system. A key difference is witnessed between non-deterministic (probabilistic) and deterministic systems.

Bitcoin, or more specifically its Proof-of-Work consensus algorithm is a non-deterministic algorithm. Once a block is added to the chain, it is not accepted as a definite new state of the system. Instead, it will trust this new version of the ledger more after a few extra blocks have been added to the chain. The required computational work then becomes sufficiently high to accept that chain as a ”truth”. This is not only important for networks with possible malicious nodes, but also fully honest systems can come up with two chains of equal length by chance. In a non-deterministic system, the probability that a version of the ledger is valid increases over time. In contrast, in deterministic systems proposed transactions are immediately rejected or added to the blockchain. This puts more stress on validating the integrity of the network, but does offer some solutions to requirements for smart contracts etc. Consensus algorithms based on the Lamport Byzantine Fault tolerance achieve deterministic consensus [9].

2.4. Transaction Capabilities

This section relates ideas that concern the scalability of transactions and usability for applications and platforms. For a large number of applications it will be important to design systems which can offer similar throughput (transactions per second) as mature market alternatives. The components deciding this are: data structures in the block header, transaction models, server storage, block storage.

2.4.1. Blockheader Data Structure

The block header consists of different components. Figure 2.4 shows a generalization of the fields usually found in a block [28].

- **Block Version**: Indicates which set of block validation rules to follow.
- **Merkle Tree Root Hash**: Blockchain also makes use of a concept called Merkle trees. These are introduced in order to save storage space. Instead of storing all the hashes of specific transactions, only the root hash needs to be stored in the block header. This is explained further below, see also Figure 2.5. For example, a block containing 4 transactions also has 4 transaction hashes h_n. The first parent node A will then contain the hash of the concatenation of the hashes of its

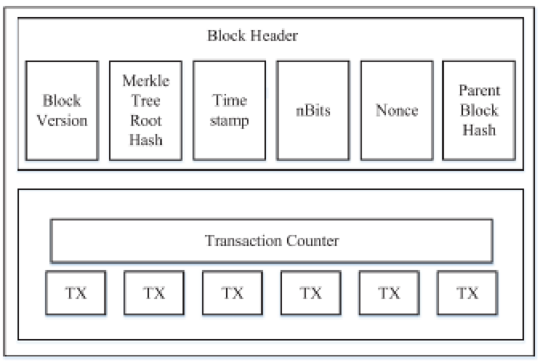

Figure 2.4: Block Structure [28]

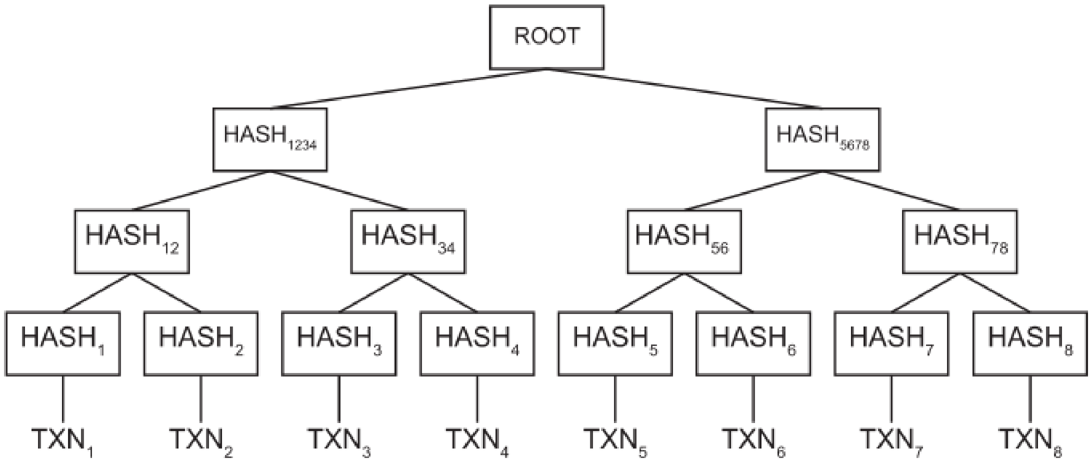

Figure 2.5: A representation of a Merkle Tree [29]

children $h(h_1, h_2)$, the second parent node B the hash concatenation of $h(h_3, h_4)$. This continues up until the top hash, also called the root hash, which is $h(h_A, h_B)$. Also for Merkle trees, it holds true that if any transaction is changed, so will the hash of that transactions and because use is made of the same hash logic, so will all the parent hash nodes. This means that two Merkle trees can be checked for equality by only considering the root hash.

The root hash can serve as an address to certain pieces of data. In a peer-to-peer network, one actor can receive a root hash pointing to a certain piece of data. It then can ask for the associated files from other nodes in the network. By constructing the Merkle tree from the data received from the network, it can be checked that the root hash is actually what is asked and not tampered with or corrupted. To do this, it is not necessary to hash the whole tree. Instead, if for example a recipient receives hash h_4 from a untrusted source, it only needs the twin leaf node h_3, and the other parent node(s), h_A to verify that the root hash is correct.

Root hashes that stay the same are of vital importance in peer-to-peer networks as it no longer matters where content is hosted. It makes verification more efficient and it provides the opportunity to distribute the responsibility of hosting files.

- **Timestamp**: the current time upon block creation.
- **nBits**: the target treshold of a valid block hash
- **Nonce**: a 4-byte field, increasing for every hash calculation.
- **Parent Block Hash**: this is the part that actually points back to the previous block and connects it to the chain.

2.4.2. Transaction Model

Unspent Transaction Output The basic principle behind the Unspent Transaction Output model (UTXO) is that every input for a transaction needs to be accounted for by one of more previous inputs representing the needed value. Transaction outputs can only be spent once. If the value of an output to be spent is lower than the corresponding previous input, the transaction delivers two outputs of which one goes to the intended receiver and the other one points back to the sender. The UTXO model includes a waiting period during which the output of certain transactions can not be used as input for new transactions. This is a way to prevent forking in blockchains and miners from spending mining rewards before the system has validated the integrity of the chain. Bitcoin and Multichain use the UTXO model.

Account Balance Model In this model every node has its own balance which is updated after a transaction is executed. If a node wants to make a transaction, validating nodes only have to check the global state to check if the balance of the sending node is equal or higher than the value of the transaction. The system then deducts that value from the sender and will then add that amount to the balance of the receiver. The Account Balance model was developed to offer a more intuitive model for developers implementing complex smart contracts, especially those including state information or multiple parties. Also, because only the state needs to be checked the process is more efficient. A downside of this model is that there are extra measures necessary to overcome the double spend problem. Next to that, with global balances, privacy may become more of an issue for the users.

UTXO+ The UTXO+ model is an attempt to stay close to the UTXO model but offers more support for complex smart contracts operations. Blockchains using this model, like Corda and Chain Core, mix data structures from the previous models. They adopt virtual machine supporting operations in Turing-complete code, but the EVMs are stateless.

Key-Value Model The key-value model is a more advanced version of the previous data models since it is able to store more variables in the state of the blockchain. This allows for different behaviour (UTXO/Account Balance) depending on the needs of the applications on top of the blockchain.

2.4.3. Server Storage

It is not always possible to have a system layout in which all nodes can deliver equal or adequate storage space to save a ledger, computing power or bandwidth constraints. To accommodate for that, two possible layouts for system storage exist: full node only and thin node capable [9].

In **Full Node Only** systems, every node contains the same information. This creates a big information redundancy, making the system more resilient to attack scenarios.

Thin Node Capable systems offer the opportunity for some nodes to store only a specific set of information on the blockchain. This improves scalability as more types of machines are able to join the network, but it could make the system less resilient to attacks.

2.5. Infrastructure

2.5.1. Classification

The original Bitcoin blockchain was the dream of Nakamoto, a fully public and decentrally controlled ledger. However, over recent years different architectures and ways of working have been proposed. It is common in literature or other sources to see blockchain architectures classified in the 4P framework (see Figure 2.6), but there are also a lot of sources using an only one-dimensional framework, where they either juxtapose Public versus Private, or Permissionless versus Permissioned. Then they often equate Public to Permissionless and Private to Permissioned. Bitfury Group and Garzik [30] differentiates between them on the third level of access, the creating of new blocks and adding them to the blockchain. In a permissioned blockchain the third level of access would be restricted to a limited set of actors, but these actors could grant read access to clients or regulators.

Blockchains can be classified based on access to the blockchain data [30]:

- **Public (Open)**: There are no restrictions on reading blockchain data (which could still be encrypted) and submitting transactions for inclusion into the blockchain.
- **Private (Closed)**: Direct access to blockchain data and submitting transactions is limited to a predefined list of entities.
- **Permissionless**: There are no restrictions on identities of transaction processors (i.e. users that are eligible to create blocks)
- **Permissioned**: Transaction processing is performed by a predefined list of subjects with known identities.

The framework by Hileman and Rauchs (2018) uses this classification to differentiate between public permissionless, public permissioned, consortium and private permissioned blockchain systems, see Figure 2.6. They specify this by looking at how the Read, Write and Commit rules have been set up. Read involves accessing the ledger and seeing transactions, Write is generating transactions and sending them to the network and Commit rights can update the state of the ledger.

Blockchain types			Read	Write	Commit	Example
	Open	*Public permissionless*	Open to anyone	Anyone	Anyone*	Bitcoin, Ethereum
	Open	*Public permissioned*	Open to anyone	Authorised participants	All or subset of authorised participants	Sovrin
	Closed	*Consortium*	Restricted to an authorised set of participants	Authorised participants	All or subset of authorised participants	Multiple banks operating a shared ledger
	Closed	*Private permissioned ('enterprise')*	Fully private or restricted to a limited set of authorised nodes	Network operator only	Network operator only	Internal bank ledger shared between parent company and subsidiaries

* *Requires significant investment either in mining hardware (proof-of-work model) or cryptocurrency itself (proof-of-stake model).*

Figure 2.6: 4P Framework [31]

The most important difference between open and closed systems are related to their security and threat model. Public permissionless blockchains have to deal with a lot of unknown actors, which could behave in a malicious way. It takes a lot of effort to incentivise participants to behave honestly and keep the network censorship-resistant. On the other end of the spectrum, closed permissioned systems know all the actors and trust them to behave honestly. This trust is upheld by off-chain legal contracts which penalize illegal behaviour.

2.5.2. System Architecture

Blockchain is still very much under development and standards are still lacking. In network research, it is common to model a network in a layered abstraction architecture inspired by the Internet and its OSI Model. The OSI Reference model was originally created by the International Standards Organization (ISO) to provide a set of design standards for equipment manufacturers so they could communicate with each other to achieve open systems interconnection. Leading figures in the blockchain community suggest that blockchain development could benefit from such standards [32].

Two models are suggested by Platt [33], see Figure 2.7 and by Belotti et al. [34] which is inspired mostly by the work of [35][36], see Figure 2.8.

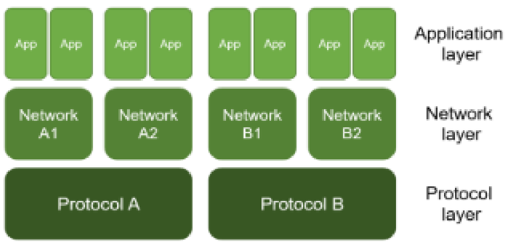

Figure 2.7: Infrastructure Architecture Abstraction [37]

The most noticeable difference is that Platt uses three layers, while Belotti et al. use five. This is caused by the fact that Platt groups some functionalities together in the Protocol layer, which are separate in the other model. This also changes what they attribute to the Network Layer, but the Application layer is the same in both models.

The protocol layer in Figure 2.7 represents the core functionalities of the blockchain system. This is where the data structure and the consensus algorithm is defined. When people talk about blockchain platforms like Bitcoin or Ethereum, this layer is most interesting in terms of differences.

The network layer defines the peer-to-peer communication between nodes. The network can be built using a standard core protocol, or multiple modular building blocks. This also determines access and permission management. Identity and permission management consists of four components [38]:

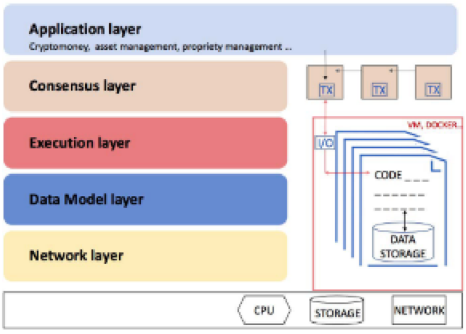

Figure 2.8: Infrastructure Architecture Abstraction [34]

- Identification: involves assigning a person or a machine as the responsible party for certain actions.
- Authentication: this process is the means used to prove the right to use an identity, take on a role or prove possession of one or more attributes. Digital signatures are a part of this component.
- Authorization: is the means of expressing the access policy by explicitly granting a right.
- Access Decision: is using some combination of the other three to decide whether or not a request should be granted.

The application layer is the primary interface for the end user. It is built on top of the network and provides products and services. Private applications can be defined on open, permissionless blockchains and applications can also be ledger agnostic, which means they can operate on distinct blockchain protocols. Which part of an input is being stored on the blockchain is decided in the application layer. It implements all business logic. Users interact with the ledger through for example API's or user interfaces.

In Figure 2.8 the application layer has the same meaning. It then pulls apart the protocol layer in separate consensus, execution and data model layers. At the consensus level, the algorithm for establishing a single valid ledger is defined. It can be static or plug-and-play and it also determines node roles. Next to the choice for a consensus algorithm, a decision has to be made about the transaction process.

There are two types of transaction processes, order-execute and execute-order-validate. In an order-execute process, transactions are ordered first by using a consensus protocol and then executed by each node in the same order. This is the standard modus operandi for virtually all blockchain systems.

Androulaki et al., developers of Hyperledger Fabric, attribute the following limitations to the traditional order-execute process [39]: transactions need to be deterministic to reach consensus, because they are only executed after ordering. If they are not deterministic, no consensus will be reached. To reach deterministic transactions, smart contracts have to be written in the same programming language which limits flexibility and if data is encrypted, non-permissioned nodes can not validate the system as they cannot execute the transaction. Scalability is also limited as transactions are validated in sequence.

Their execute-order-validate process splits transaction flow into three steps, which may be run by different entities. The first step is executing the transaction by a few confirming nodes (which can be trusted because it is a permissioned system) and checking its correctness, thereby endorsing it. After that it is ordered through a consensus protocol and the new state is validated by the other nodes in the network. This policy removes the requirement for deterministic transactions, making language choice more flexible and improving scalability [39][40].

In the execution layer, there are smart contracts environments like compiler, virtual machines (VM) and containers. It determines the transaction execution mode (CVM, EVM, TxVM) and the languages (Turing complete or not) for smart contract development. The Data Model layer consists of the data structure, content and data storage. A subdivision here can be made between ledger matters, which concern the transaction model or the ledger structure. Data can be stored off-chain to protect sensitive data, save on storage cost and/or improve performance and flexibility. If data is stored off-chain it means the data itself is actually not on the blockchain, but only a reference, like the hash of the data, can be added to the ledger. This storage can be done on any system, for instance cloud-based storage solutions. In terms of security, in the data model a decision can be made between traditional encryption or Zero-Knowledge Proof. At the network layer, similarly all network and transport protocols are defined.

2.6. Smart Contracts

Smart contracts are scripts stored on the blockchain. Contracts are triggered by addressing it using its unique address on the chain. The contract is executed independently and automatically in a predefined manner on every node in the network, according to the data that was included in the trigger transaction [41]. This implies that every node is running a virtual machine, and the network acts as a distributed Virtual Machine.

Christidis and Devetsikiotis make some observations about the properties for smart contracts on blockchains. It is important to note that smart contracts maintain their own state and can manage assets on the blockchain. In order to do this, the system needs to be implemented using a Account Based ledger model [41].

Smart contracts are triggered by addressing the unique identifier of the contract. Depending on the given input, the contract will respond in a certain way. This output should be deterministic in order for the network to be able to reach consensus, meaning that the contract should give the same output for the same input every time. It is also important that all possible inputs have a defined response. This prevents unexpected behaviour from the contracts and the creation of disputes between the involved parties.

The code of a smart contract is on the blockchain and it is therefore visible for all participants of the network. This makes the proper code/agreement verifiable for all nodes. Given that all transactions on the contract (as it is on a blockchain) are done using cryptographically signed transactions, all operations on a smart contract create a verifiable trace [41].

Smart contracts have the benefit of being able to inspect the code and identify its outcomes before deciding to engage with the contract, have certainty of execution since the code is already deployed on the network that neither party controls fully and have verifiability over the process since all transactions are signed.

2.7. Ecosystem

At this point, with a description of the system architecture in place, it is useful to define the different actors in a general blockchain ecosystem. Hileman and Rauchs [31] identify four categories of actors in the blockchain ecosystem:

- **Software and Services Providers**, the parties delivering both the core infrastructure and the applications, which can be subdivided into:
  - *Protocol Developers*: develop the core protocol layer (Platt model).
  - *Network Developers*: Build custom networks for customers.
  - *Application Developers*: Develop applications that run on top the existing network(s).
- **Operators**: entities that administer and manage a network or application.
- **Users**: participants that run a node on a network or that connect to a certain application on the blockchain.
- **Peripheral Actors**: all other actors that are not involved in building or operating a network.
  - *Consortia*: group of separate entities that collaborate on blockchain technology (either technology specific, use case specific, industry specific or cross-industry)
  - *Researchers*
  - *Other*: This group includes Legal, Education and Training, Investors etc.

2.8. Platforms

The following is a short introduction of well-known blockchain platforms. The list is by no means exhaustive, but it serves as a way to show how various blockchain platforms can differ from each other.

2.8.1. Bitcoin

Bitcoin was the first blockchain system, launched in 2008 by Satoshi Nakamoto [5]. It is a public and permissionless system. This was intended as the goal was to create a platform for public payments without the need for an intermediary. This design goal makes it by default unsuitable for private, permissioned use cases. Bitcoin uses Proof-of-Work as its consensus algorithm.

2.8.2. Ethereum

Ethereum is one of the most well-known blockchain platforms and seen as the second generation of blockchain systems after Bitcoin. It is an open-source and public permissionless system with smart contract functionality. It is governed by the community of Ethereum developers and is intended as a general platform offering functionality for all kinds of use cases. It was the first platform to offer the smart contract functionality, but nowadays this has been implemented by many other platforms as well.

Ethereum has its own cryptocurrency called Ether and can also be used with tokens to implement smart contracts. These smart contracts are written in the built-in programming language Solidity. For consensus, it uses a variation on Proof-of-Work, but in the community an argument is being made for Proof-of-Stake consensus in order to tackle the high requirements on bandwidth.

2.8.3. Hyperledger

Hyperledger is an open-source project initiated by the Linux Foundation. It consists of several distributed ledgers and also some libraries and tools. The platform aims to create an enterprise-grade, open-source distributed ledger. Most ledgers are focused on permissioned business applications across a range of different industries, rather than a specific use case. The section below introduces the six different ledgers [42].

Fabric Fabric is intended as a foundation for developing applications or solutions with a modular architecture. It allows components, such as consensus and membership services, to be plug-and-play. It is aimed to be applicable to a wide range of industry use cases.

Sawtooth Hyperledger Sawtooth offers a flexible and modular architecture which separates the core system from the application domain, so smart contracts can specify the business rules for applications without needing to know the underlying design of the core system. Hyperledger Sawtooth supports a variety of consensus algorithms. It is focused on reducing the computational resource consumption. It does this by using Proof-of-Elapsed-Time consensus. Any device with a modest CPU can take part in validating on Sawtooth, making it useful for IoT devices.

Grid Hyperledger Grid intends to provide reference implementations of supply chain-centric data types, data models, and smart contract based business logic – all anchored on existing, open standards and industry best practices. Grid is not a blockchain platform, but it is rather more like a middle layer between blockchains and applications. It can be used with different blockchain platforms. Developers use the Grid framework to build applications on top of these platforms, which is done in a standardized, modular way with focus on fast supply chain use case development.

2.9. Blockchain Decision Schemes

The literature describing when blockchain makes sense is expanding. Many sources from both academic and grey literature provide decision frameworks to check the technical necessity of a blockchain solution. One of the most influential papers has been written by Wust and Gervais [8], which tries to answer the question when to use a blockchain and differentiates between blockchains according to the 4P Framework. Koens and Poll [43] also noted the emergence of various papers on the subject and chose to compare them. They analyzed 30 schemes and show contradictions between the schemes. As a remedy, they propose a new decision framework based on the existing schemes which takes into account those contradictions and is more susceptible for alternatives to blockchain [43]. As this work included 30 sources (including the one by Wust and Gervais), this paper is described extensively to see which factors are of importance. The other interesting sources described next which provide additional value are the framework of Belotti et al. [34] or from a supply chain perspective by [44].

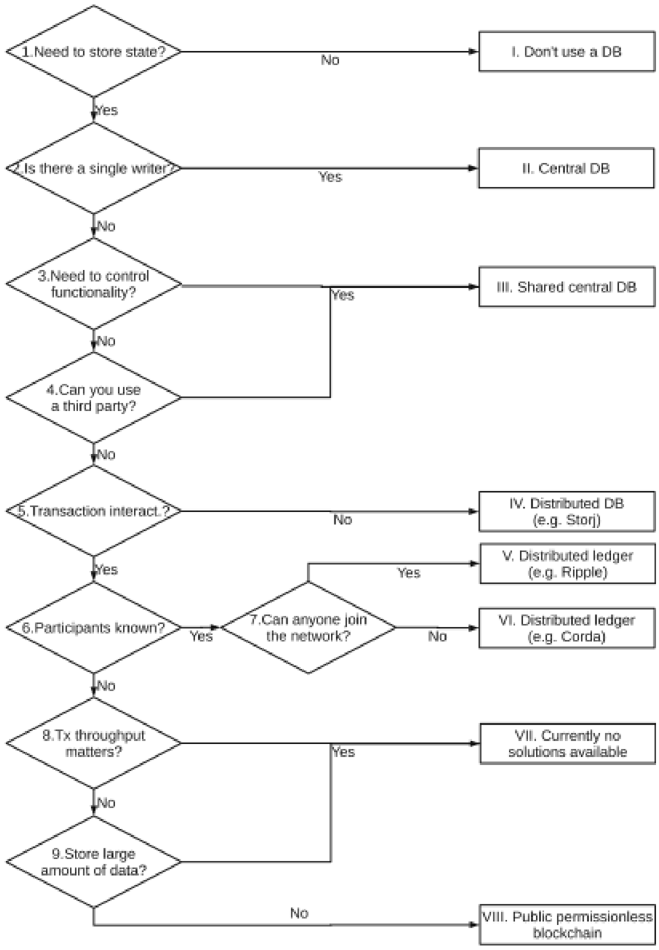

Figure 2.9: Blockchain Decision Framework by Koens and Poll ([43])

In the decision framework in Figure 2.9, the first questions are easy to answer. For a particular application, it is straightforward to establish if there is a need to store state and if there are multiple writers. The third question whether or not you like to control functionality is somewhat vague. With controlling functionality they refer to things like setting rules on how database permissions are set, how the data is stored or how the database can be queried. In this scheme that decision is made by one party.

A difficult question is the next one, number 4: Can you always use a trusted third party? This question is double-edged as it first requires to assess whether there even is a third party along the entire chain which could be used. Next to that, it requires a trusted party, which means defining what trust entails in this scenario and agreeing between all stakeholders that this party is indeed trusted.

The next question (number 5) about transaction interaction also requires more explanation, as it is not obvious what is meant with this. The concept is defined by Greenspan [45], which is adopted by Koens and Poll. It means that transactions have some interdependence. For instance, when Party A sends money to Party B, this is a transaction increasing the account balance of A. The dependent transaction which is created is the deduction of the account balance of B. Both need to happen for the entire transaction to be valid, and if one does not occur, the other one will also not happen. This example is also applicable to trade scenarios, where the ownership of a physical asset transfers. A good case which indicates some transaction interaction is where transaction from different writers are cross-related but still independent. This happens when several writers validate different aspects of a specific entity. The transaction technically could stand alone, but blockchain provides a useful way to bring everything together [45].

The next question (number 6) if the participants are known diverges the flow between permissioned and permissionless blockchains. In their nomenclature, only a fully public, permissionless system is called a blockchain, whereas the permissioned systems are called distributed ledgers. If the participants are known, the question if anyone can join differentiates between public permissioned and private permissioned systems.

The last questions (8 and 9) concerns current limitations of blockchain, such as transaction throughput and data storage space, but seeing the pace of development, one can wonder how long these questions will remain relevant.

Belotti et al. [34] provide an extensive review of blockchain technology and break its decision scheme up in three parts: *When?, Which?* and *How?*, see Figure 2.10. The first questions about state and multiple writers are equal to all other schemes. It differentiates a bit on the third question, asking *"Who do you entrust with maintenance of the ledger?"*. It present three options for this: an external third party, a group of selected actors or the public community. Choosing the external party, leads to a recommendation of using traditional databases like the other frameworks. If the answer is only the public community, it already points to using a permissionless blockchain. The third option, a group of selected actors, leads to a little more complex flow, as it raises the point whether if public verifiability is required. This question is included by Wust and Gervais, but is omitted by Koens and Poll as they do not consider it to be a design question. This could be explained by the fact that they view only public permissionless systems as blockchains. If the answer is yes, it points to open permissioned blockchain systems. If it is not required, a trade-off has to be made between performance, cost, adaptability and specific blockchain features such as failure resistance. Choosing blockchain leads to a new flowchart, pinpointing the exact technology you need.

Belotti et al. also answer a third issue, which is exactly which blockchain platform to use after deciding on the system type. The first question is to build your own blockchain framework or to leverage existing platforms. In the existing platforms, there is an important differentiation between open-source and cloud-based solutions, Blockchain-as-a-Service (BaaS) offerings. BaaS allows customers to build and host their own applications, smart contracts and functions while letting external providers manage the required infrastructure. The authors then make an extensive review of modern blockchain platforms, noting important architectural features and performance measures. From here, it is really a choice made by the customer based on trade-offs. The authors suggest that the choice is made based upon seven aspects:

- Cryptocurrency: Main ingredient in permissionless and open permissioned system, where they ensure ledger auditability and immutability.
- Node roles: In some systems all nodes are identical, while in others their responsibilities change in order to achieve better system efficiency.
- Execution: Difference between parallel and sequential execution.
- Performance: It is hard to find metrics which compare blockchain systems fairly, given their vastly different natures. Dinh et al. [36] offer an evaluation framework for private blockchains. They compare on execution time, latency and throughput.
- Smart Contract Language: There are numerous programming languages which can be used to implement smart contracts.
- Consensus: the choice of consensus influences a lot of design choices. The flexibility between consensus algorithms can also be important, which for most platforms is limited.
- Security: some platforms leverage trusted hardware to improve the trade-off between performance and security cost.

In a report published by the Boston Consulting Group and MIT Media Lab [44]) the decision to pursue blockchain initiatives in supply chain is directed along two dimensions: the value of automation (speed, efficiency) and the value of trust (highly related to the number of parties involved in transactions). The report contrasts the choice for blockchain mostly with control towers. Control towers are a central hub with the required technology, organization and processes to capture and use data to provide enhanced visibility for short- and long-term decision-making aligned with strategic objectives [46].

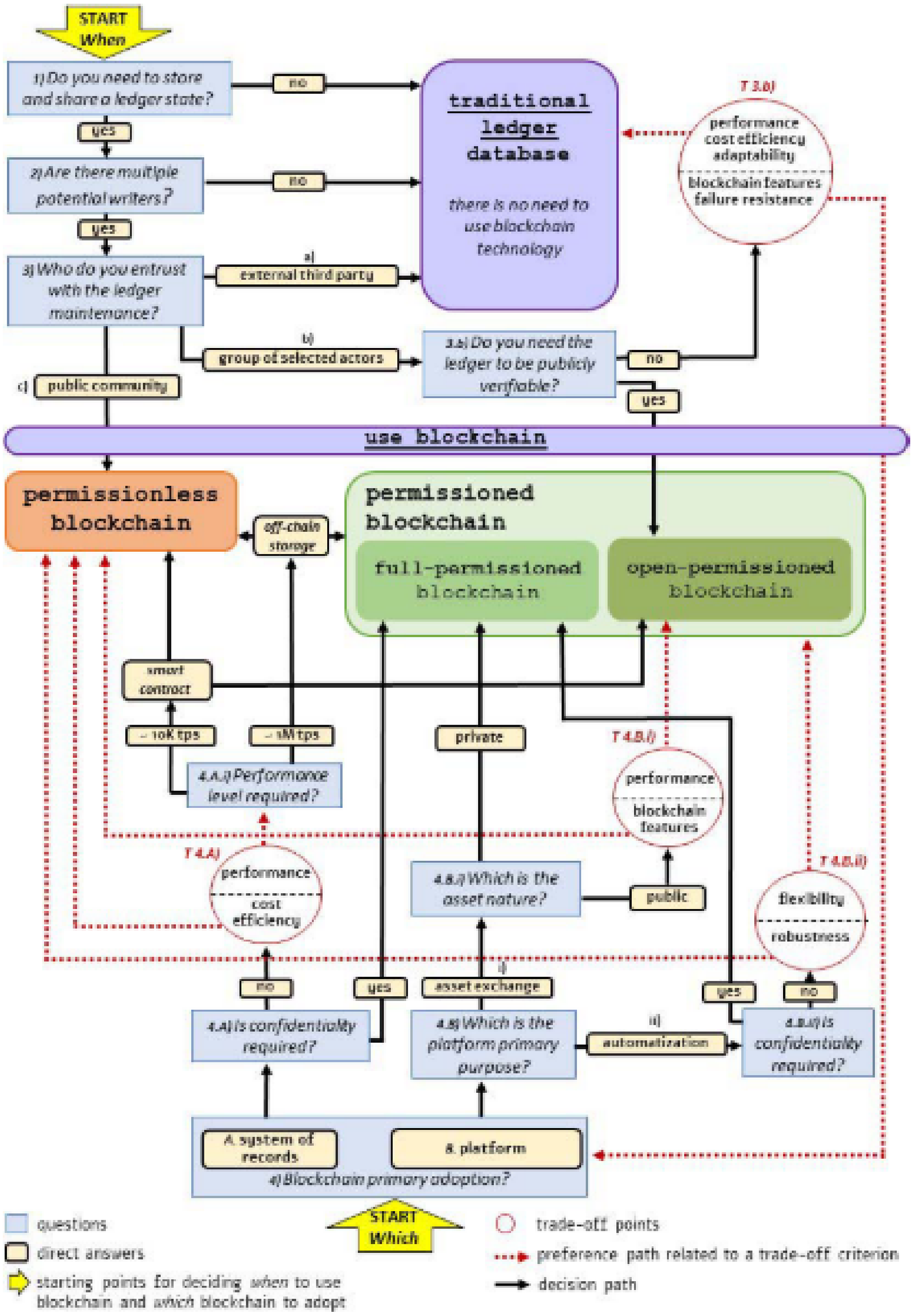

Figure 2.10: Blockchain Decision Framework by Belotti et al. ([34])

Both technologies promise to deliver end-to-end visibility and the ability to automate task execution. The decision mostly depends on the importance of trust and whether the benefits offset the sacrifice of centralized control. Their research points to the area where the value of both automation and trust are high as being the sweet-spot for blockchain applications. A large number of (often changing) players means that trust issues become more important. Where automation is of less important they note some niche applications, but especially for applications where trust is of low value, the authors do not see use cases.

2.10. Key Points

The key take-aways from the chapter about blockchain are that it is a technology for storing and sharing data. It relies on cryptographic principles for security, making way for the transition from centralized systems to decentralized systems, where decentralized means that there is no single authority deciding on the state of the system.

The way that blockchain achieves immutability is explained and the different consensus algorithms have been presented to illustrate the differences between blockchain platforms and its benefits and challenges. Platforms can also be classified according to the 4P Framework, dividing between Public and Private, and Permissioned or Permissionless blockchains. Design choices lead to different use cases. From this point onwards, the knowledge presented in this chapter is assumed as known, although it is acknowledged that the depth of this chapter goes beyond the level needed for understanding the remainder of this report.

3
Blockchain and Supply Chain

This chapter aims to connect blockchain technology to contemporary supply chain issues. It does this by first providing an insight into academic literature reviewing these supply chain challenges, with a special focus on information sharing and interorganizational systems. Then the literature on blockchain use cases in supply chain management is presented. Trough these literature and use case reviews, the main research question of this thesis is addressed, as well as questions 2, 3 and 4.

3.1. Supply Chain Review

It is important to understand what the issues are in the supply chain domain, irrespective of any technological paradigm, before deciding on urgency of some use cases of supply chain traceability. From a business perspective, it needs to be add value. In this section a quick overview is given of supply chain issues or developments. This overview will then be used to connect to blockchain development, therefore extra attention is given to papers or sections referring to supply chain collaboration or IT integration.

A supply chain encompasses all activities needed to convert raw materials into final products, from sourcing through component manufacturing and final assembly to distribution to end-markets, and including all necessary material handling and storage activities. It also includes the handling of return flows of products and the possible re-use of materials and components, so-called closed loop supply chains [1].

Supply chain management comprises the planning and management of all activities involved in sourcing and procurement, conversion, and all logistics management activities. Moreover, it also includes coordination and collaboration with channel partners, which can be suppliers, intermediaries, third party service providers, and customers. In essence, supply chain management integrates supply and demand management within and across companies [47].

Zijm et al. present seven key aspects of supply chains and logistics [1].

- *Availability of materials, products and information*: This is the most basic notion of supply chain management. Its primary objective is to ensure the timely availability of the right quantities of raw materials, parts and products together with all information needed for further processing at their destined locations. Supply chains almost always encompass various companies (see Figure 3.1), so coordination of the goods flow throughout the supply chain requires synchronization of activities controlled by different stakeholders, each with their own objectives.

- *Cost-efficiency*: For a long time the goal has been maximum output with minimal material and manpower (cost) consumption. However, over the last years the realization has appeared that reducing costs in one part of the chain might increase cost upstream and therefore be undesirable.

- *Customer Orientation*: Since the 1960's, the market has developed from a push market to a pull market. Consumer demand drives product development instead of the other way around, which led to customer differentiation, shorter product life cycles and tailored solutions [49].

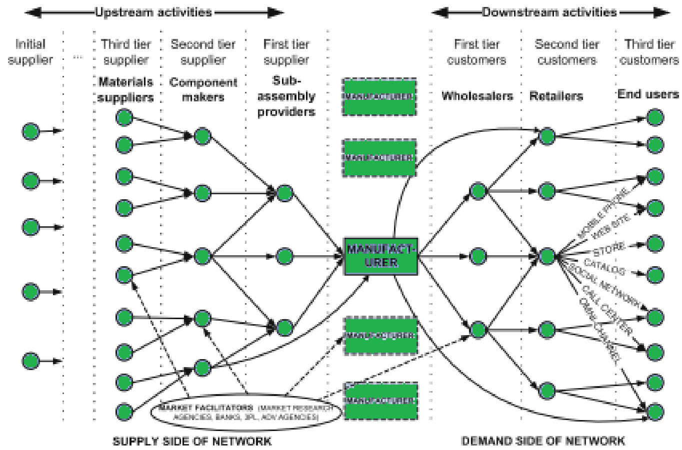

Figure 3.1: Supply Chain Tier Model [48]

- *Speed*: With rising customer expectations, came a increased importance of timeliness delivery of products. Traditionally, this was solved by keeping high inventory levels, but this turned out to be a resource inefficient practice. Final demand variation may furthermore be amplified upstream, with large stocks and inflexibility as a result, which is known as the bullwhip effect. Short lead times and supply chain synchronization have been demonstrated to combat these problems.

- *Effectiveness*: Lean production refers to the ability to limit activities in a supply chain to those that only add value to products and services as experienced by a customer, and avoiding any activity that can be considered as waste.

- *Environmental Sustainability*: Over the last decade, the industry realized that it puts high stress on the environment by means of emission of hazardous materials, congestion and noise. Furthermore the usage of scarce and non-regenerative materials is also a source for concern.

- *Social aspects*: There is growing attention for the need to create safe and socially acceptable working conditions, but so far these conditions have not been realized globally.

They also note digitization as one of the most important trends impacting supply chains. The explosive growth in the production and usage of data heavily influences supply chain activities. Increased data transparency may help to improve safety and security in supply chains, particularly to diminish the risk of fraud. The goal for each stakeholder in a complex, heterogeneous supply chain is to be able to verify all the required information, to access and modify the data to the extent authorized, and to ensure a secure and uninterrupted logistics process such that the goods are delivered from the producer to the receiver without any delay or loss in any link in a complex chain [1].

In recent years, business activities are taking place in a more dynamic and uncertain environment. This has impacted supply chain as a sector, from product development, to manufacturing, to reverse logistics. The satisfaction of the customers is seen as the most important driver of success, and their expectations towards certain service levels has risen. Customers expect fast and correct service, while also having the flexibility to switch to another supplier quickly, enabled by their improved information power, given to them by the resources available online [1][49].

To address this changing and increasingly uncertain environment collaboration within the supply chain has increased by pooling and integrating resources of suppliers and customers. It has been an area of research since the early 1990's, but still problems exist with the implementation of collaboration [50].

A literature review done by Panahifar et al. identified and assessed interrelationships between various characteristics of information sharing and trust and their criticality for effective information-centred supply chain collaboration and the performance of the firm [50]. They studied four potential enablers: information security, level of trust, information accuracy and information readiness. Their conclusion is that there is significant evidence that information sharing is important for effective collaboration, and the positive effects of collaboration on firm performance. Their findings also include that secure information sharing, which concerns both security from a technical perspective as from a decision-making guideline preventing leaking of proprietary information, has a positive effect on information accuracy and a negative effect on trust. This is explained by the fact that if companies need to share sensitive information, they will be less trusting and up their security protocols.

Furthermore they note that more accurate the information directly enhances the level of trust. Trust indicates if a supply chain partner is willing to share information and rely on information supplied by other trusted partners. Trust enables the flow of information which impacts the success of collaboration. Trust is also increased by information readiness, which concerns the availability and the usability of information. Of the studied enablers, they found that three had a significant effect on effective collaboration (and thus the firm performance):

- Information Sharing Security
- Trust
- Information Readiness

Information sharing security, trust and information readiness were all significant, except for information accuracy. This last finding may be surprising, but is supported by Claassen et al. [51] in their study of Vendor-Managed Inventories, an application of supply chain collaboration. They found no significant relation between information quality and perceived Vendor Managed Inventory success, but did find a strong correlation. This suggest that they are related, but it has no positive effect over and above the positive effects of the other enablers they studied (quality of ICT, sharing intensity and relationship quality) [51].

It is essential that the information sharing system between partners is secured. Appropriate access and control mechanisms should be implemented to ensure security. Smith et al. [52] review collaboration in an IT-enabled supply chain from an information security risk perspective . They define supply chain information security risk as degradation or disruption to a supply chain's infrastructure or structural resources from the successful exploitation of IT vulnerabilities by threats within an organization, within the network or in the external environment [52]. The increased usage of IT systems for information sharing mitigates traditional sources of supply chain risk while simultaneously increasing the exposure of each interconnected organization to sources of IT risks. Their findings shows an increasing relation between the number of partners, level of integration or amount of information shared and the number of IT related incidents. They pose that a cost-benefit analysis should be made before deciding to advance IT enabled collaboration.

Ralston et al.[53] describe the factors influencing supply chain collaboration in three categories: internal factors, relational factors and technological factors. Internal factors include willingness to collaborate, headlined by top management commitment, willingness and ability to change or adapt and having a market/customer orientation. Relational factors mentioned are a relationship orientation (the proactive creation, development and maintenance of relationships that result in mutual exchange of value), acceptance that information has to be shared and that decision making will be shared, investment into relations and the ability to communicate between partners (giving open and multi-way feedback). This is often influenced by enabling technology. Technology can enable communication. Electronic methods have increased accessibility and brought partners closer together. It can enable parties to share basic or routine tasks and reduce operational overhead. A key factor is the effective interfacing of partner's technology platforms [53].

Building on that, it is interesting to see how IT-enabled interorganizational systems fit into this. Interorganizational systems (IOS) are defined as information and communication technology-based systems that transcend legal enterprise boundaries [54]. The boundary spanning aspect implies a level of cooperation and coordination well beyond that of the traditional relationships that exists between organizations. But even IOS that started out with cooperational intents can turn into conflict by opportunistic, uncollaborative behaviour by one of the parties [54].

Zhang and Cao [55] observe that interorganizational systems have often been mentioned as a necessity for collaboration success, but that these studies fail to acknowledge the cultural context it exists in. They also observe that studies on IOS often mention integration, but rarely their value to communication or joint knowledge creation. Their study explores the impact of collaborative culture and interorganizational systems on supply chain collaboration [55]. Their results show a positive relationship between the existence of a collaborative culture and IOS appropriation, and between culture and supply chain collaboration. Their findings also show a positive relationship between IOS appropriation and collaboration and a mediating effect of IOS on the relation culture-collaboration, but their findings did not show a moderating effect of culture on the relation IOS-collaboration.

Zhang et al. [56] discuss interorganizational systems and their deployment strategies, focusing on the trade-off between depth (the level of integration with suppliers) and breadth (the diversity and scope of use cases implemented). They conclude that both are beneficial to the operational performance of the firm, and that their deployment should be balanced to improve competitive performance, i.e. better allocation of firm resources and benefit from both broad and tight interorganizational relationships. Focusing on one dimension does not help to improve competitive performance.

Intermediate Findings

The preceding section is a collection of sources on supply chain management, supply chain management collaboration and information sharing, and interorganizational systems. The most important findings are the key aspects of modern supply chains, and the the impact digitization will have on supply chains. It was noted that information transparency and verifiability by all stakeholders will increase supply chain safety and security.

It was found that information sharing has a positive impact on supply chain performance and that the most important enablers are information sharing security, trust and information readiness, and that accuracy and readiness positively influence trust. It was also found that risk increases with the size of the network and the confidentiality of the information.

Supply chain collaboration was also shown to be influenced by internal, relational and technological factors. Most importantly it noted the willingness to collaborate and share valuable information, and the role which technology plays in this. Then it was shown that technology implementation (IOS) success is also influenced by these factors, to underline the importance of a joint commitment between the supply chain partners.

3.2. Blockchain and Supply Chain

Kshetri [57] lists some key objectives of supply chain management based on previous research. This list includes the factors cost, speed, dependability, risk reduction, sustainability and flexibility. He mentions that blockchain facilitates valid and effective measurement of outcomes and performance of key supply chain processes, especially in the food industry. A key element of the blockchain model is that all transactions are auditable, which is important in gaining the trust of all interested parties, furthermore it can increase security. Supply chain is in a unique position for the development of blockchain, as the average complexity of supply chain networks make the existence of trusted central intermediaries impossible.

Akyuz and Gursoy provide a structured overview of the potential impact of blockchain on supply chain management [58]. They find that the technology is expected to provide an accurate and trustable transaction infrastructure as well as true visibility and traceability across partners. Because of this transparent and trustable multi-partner ecosystem, they state that blockchain will likely accelerate and strengthen the realization of a collaborative, IT-based network paradigm [58]. The impact of blockchain on supply chain will be further discussed below in the following three sections:

- Transparency, Visibility and Traceability
- Automated controls and Smart Contracts
- Trust Building and Collaboration.

3.2.1. Transparency, Visibility and Traceability

Traceability and visibility have always been important in providing high value services to customers. It provides a true competitive advantage in order to be able to know by whom, when and where a product was processed. It allows for better planning and process synchronization, and it improves decision-making capabilities for customers. Good upstream visibility is currently lacking [48].

The terms transparency, visibility and traceability are often used in relation to blockchain. Their exact use differs slightly between sources and therefore the meaning becomes a bit obscure. Unnu et al. define transparency as the disclosure of information available to supply chain participants and stakeholders. Traceability is defined as information being available to trace the history, application or location of an object. Traceability is thus an enhanced version of transparency and requires connections between the data collected and the physical asset or service. Disclosure of traceability creates transparency, but transparency does not necessarily imply that traceability is achieved [59]. It is therefore considered a subset of transparency. They view visibility as synonomous to transparency.

Several authors provide the case for improved transparency and traceability in supply chains (using blockchain) [58][60][61][62], often linked to quality management [44][63][64], product provenance [58][62][65], preventing fraud and counterfeiting [58][62][66] or handling special traceability requirements [58]. Abeyratne and Monfared state that in an increasingly complex supply chain, a disruption in the upstream supply chain can have a massive effect on the rest of the chain, resulting in potential financial losses and/or reputation damage [60]. Supply chain visibility is a key business challenge, with most companies having little or no information on their own second and third tier suppliers. End-to-end transparency can help to model the flow of products, enabling new data for analytics towards operations, risk and sustainability [60].

They also state that, traditionally, if there is any party tasked with the flow of trusted information between parties, this would be non-profit governmental entities or other third parties through centralized information depositories. They see this single point of failure as a weakness. They note blockchain as a solution to this problem [60].

The tracking and traceability that blockchain enables has also been mentioned to improve sustainability practices on both environmental and social levels [67][68][69]. The increased transparency will put more pressure from customers to make ethical decisions on companies, but in turn also enable them to make more informed decisions about ethical manufacturing practices. Currently this information is lacking and companies have to rely on spot audits or self-evaluation [60].

Hastig and Sodhi performed a thematic analysis in their literature review on blockchain for supply chain traceability [70]. They focused on the business needs for traceability systems and on the critical success factors influencing traceability implementation. Figure 3.2 shows their results on the drivers for traceability. These are as follows:

- Meeting Stakeholder Needs, which can be subdivided in transparency, compliance and demonstrating integrity.
- Curbing Illicit Business Practices, preventing dishonesty, fraud, corruption or criminal activities.
- Improving Sustainability Performance, where companies require their traceability systems to tackle social issues, environmental issues or the adoption of sustainable practices.
- Increasing Operational Efficiency: Business can require the system to improve efficiency by error elimination, process streamlining, visibility and improved order fulfillment.
- Enhancing Supply Chain Management, which could be impacted by a (blockchain) traceability system, by improving partner cooperation, improving supply chain information flow, the governance of supply chain partnerships or establishing a competitive advantage.
- Sensing Market Forces and Trends: Companies could look towards traceability to help them with issues on globalization, supply chain risk, business innovation or other trends.

The potential of blockchain in the traceability use case is heavily related to IoT and sensor-related developments [48][60][71]. These sensors are capable of capturing a large variety of valuable product data ranging from temperature, to location to sound. The rich product profiles which these technologies provide still needs to be authenticated, verified and securely collected and exchanged. Blockchain can play an important role in this. Kshetri [71] notes that the much needed security improvement on certain IoT network can be delivered by blockchain-based identity and access management. By storing the device configuration on the chain, unseen digital tampering with the device is prevented.

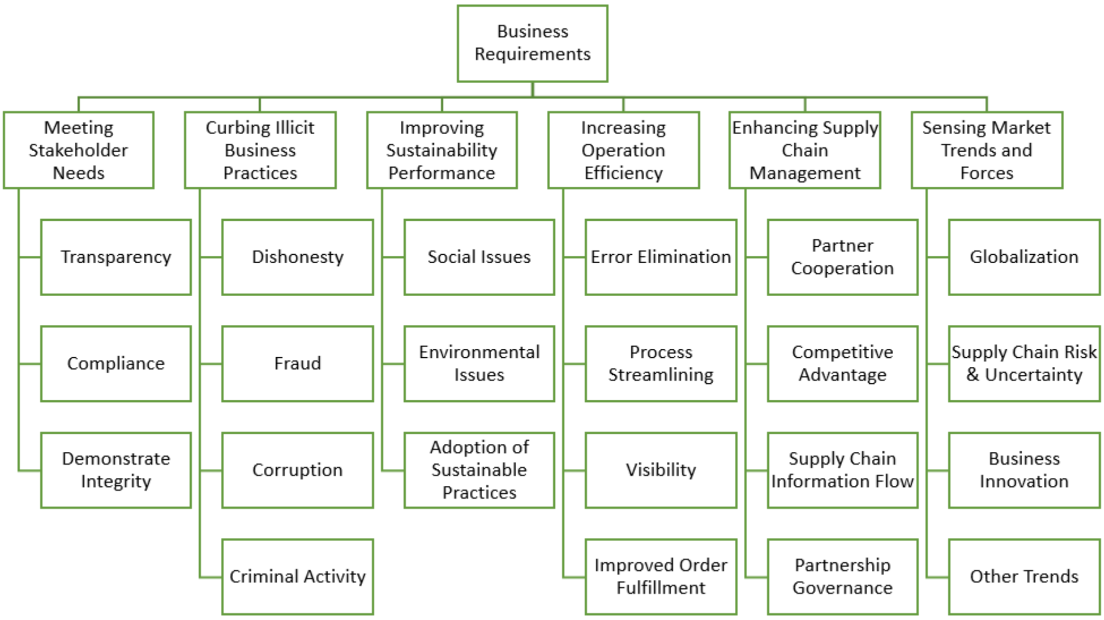

Figure 3.2: Business Requirements for Traceability in Supply Chain [70]

3.2.2. Automated Controls and Smart Contracts

In a smart contract based on blockchain, the terms of the contract are formulated in code, after which the smart contract is placed on the blockchain on which it self-executes automatically without the assistance of the contracting parties when pre-defined conditions are met. It is capable of preventing unauthorized changes of its internal logic and a party therefore can not prevent the execution or unlawfully alter its content [72].

According to Dujak and Sajter [48], the technology itself is still in the testing phase. It can be expected to become a long-lasting artefact in the near future. The use of smart contracts has several benefits[48]: there is no need for a third party, which makes any transaction faster and cheaper. It reduces the amount of human involvement giving less opportunity to human error and disruption. It could be used during any form of logistic or financial transaction. Various parameters like quantity, lot size etc. can be represented in code and can be automatically checked at any point during a transaction. This provides real-time validation of documents and contributes to document-intensive processes like customs clearing. It increases visibility and trust in documentation across stakeholders [58].

It could also support the establishment of supplier relationship management. Embedding the dynamic features into the contracts allows the execution of automated controls to check whether the contractual conditions are fulfilled during material and money-related transfers [58]. This is useful for handling the complexities of supply chain contracts which often involve multi-party agreements with various regulatory and logistics-related constraints. Multiple contracts with variable contents can be managed efficiently and simultaneously with the guarantee that many automated checks are accurately made, which is a very significant improvement from a supplier contract management perspective.

It is also suggested for smart warehousing and smart logistic solutions. Shipments can be equipped with sensors and a smart contract on the blockchain. Any logistics provider that is willing to accept the terms of the contract, can take on the deal by interacting with the sensor and automatically transfer ownership and trigger certain financial obligations [73].

A more extreme implementation of automated controls with smart contracts is the so-called Decentralized Autonomous Organization (DAO). A DAO is an organization that is run through smart contracts [74]. DAOs can be constructed in such a manner that they can function without human managerial intervention, as long as the underlying smart contracts are robust and Turing-complete. Real world tests with DAO have been done, but none have survived. It suffers from legal uncertainty, malicious behaviour and the complexity of coding entire organisations into robust contracts [74].

3.2.3. Trust Building and Collaboration

Blockchain can serve as technological fabric, interconnecting a set of companies and thereby facilitating information exchange across organizational boundaries [75]. The upside for blockchain to enable collaboration and information between organizations has also been mentioned by [76][77][78][79]. Seebacher and Schüritz state that the decentralization aspect will require cooperation and trust is an essential aspect that has to be ensured in order to facilitate collaborative processes [80].

Regarding blockchain-enabled systems, many have written about the implications of the technology on trust. It has been mentioned to enable trustless transactions, allowing strangers to confidently trade with other strangers. Some have even called it a trust paradigm shift, removing the need for trust in another organization and instead replacing that with trust in technology [75][81][82].

McKnight et al. [83] investigated the concept of trust in technology, as an extra construct next to trust in interpersonal and interorganizational relationships with regard to information systems. They hypothesize that trust in technology starts with a propensity to trust, the willingness to depend on a technology across situations and technologies, and this will positively affect institution-based trust in technology. This is defined as the belief that success is likely because of supportive situations and structures. They hypothesize in turn that this will benefit trust in a specific technology and will mediate post-adoption technology use. Trusting a specific technology is reflected in three beliefs: functionality, helpfulness and reliability.

Manrique writes that trust will still play a role in blockchain systems, as users currently do not possess the advanced computer literacy to put their trust into algorithms and the fact that blockchain connected to physical assets still needs to be trusted that the data input is correct [84]. He also writes that it will force blockchain initiators to open up more, as new collaboration projects require unprecedented data sharing, making actors potentially uncomfortable [84].

3.3. Barriers

Several authors have written about the barriers for blockchain adoption. Seebacher and Schüritz [75] make the connection between blockchain and interorganizational systems. First, they provide a systematic literature review of the barriers to implementation of IOS. With further literature review and expert interviews they compare the barriers of IOS to those of blockchain technology in a similar context. They group these barriers in technical, organizational and network barriers. The result of this can be seen in Figures 3.3, 3.4 and 3.5. Saberi et al. [69] divide the challenges into four buckets: Inter-organizational, Intra-Organizational, System Related and External Barriers. Their framework does not include the technological barriers separately, but they rather distribute those challenges among the others issues. They also add challenges regarding sustainability to their framework. Wang et al. [85] use the categories organisational, user-related, technology and operational challenges. As these are pretty similar, only [75] is presented extensively to illustrate the issues.

First the technological barriers. According to Seebacher and Schüritz, the technological challenges facing IOS are:

- Lack Of Technical Capabilities involves having the skills and know-how to implement new technologies, which is always an issue. The large number of blockchain platforms, sometimes lacking documentation and general technological maturity makes this issue blockchain specific [85].
- The compatibility of new technologies with existing infrastructure is of vital importance, especially in interorganizational systems. For blockchain this complexity is increased as different platforms have different requirements [85][86].
- Industry and data standards are necessary for ensuring data transfer across organizations. Blockchain technology still does not have a standard yet, as there is no single dominant platform [75].

Second, they list the following challenges on an organizational level:

- Project Management is always a challenge in complex IT system implementation. The implementation of blockchain requires extra participants which increases management complexity [75].
- With any project, scope can increase quickly and upfront investment costs can be uncertain. Implementation of blockchain projects has by no means a clearer participation cost, so this challenge holds.

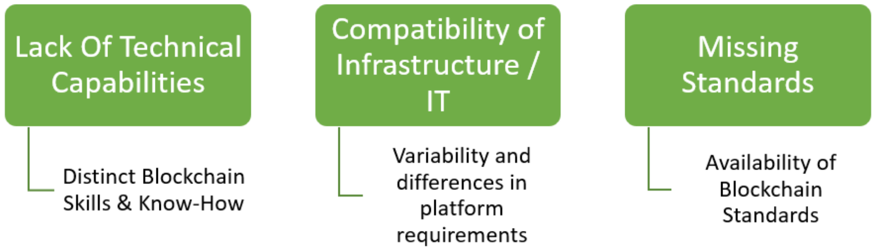

Figure 3.3: Technological Barriers [75]

- Organizational Readiness guarantees the availability of needed organizational resources for adoption. Companies often do not possess the complete knowledge to perform these implementations in-house, so they fall back on solution providers or consultants.[75][87]
- Top Management Support is a requirement for any large project being done in a company. The authors note that in contrast to many other developments, blockchain requests are often driven by top management, so they do not seem to be suffering from this challenge [75].
- Companies are afraid that any IOS implementation will just create another lock-in effect until another solution pops up. It will create multiple infrastructures, which increases maintenance cost [75].
- Legal barriers exist because organizations might be in different jurisdictions. This extends to blockchain, which in turn might cause extra legal barriers because of the disintermediation effect. It is unclear who will fulfill the legal tasks of intermediary parties [75][87].
- Technology implementation should be from a demand-pull, rather than a tech-push. Technology-driven implementation has the threat of not solving any real business issue, which is driven by technology providers selling their product, rather than a solution. For blockchain the use cases are still being determined and the choice of network stakeholders influences the potential benefits, with narrow use cases leading to limited results.
- Internal Resistance: With any organizational change, there is always a fair share of internal resistance to change.
- Missing awareness and perception of benefits hinders the development of IOS. Again the size and composition of the blockchain network will influence the benefits and therefore parties not joining the network, because of failing to perceive the benefits is a risk [75][87].

Third, the network related challenges are discussed:

- As discussed before, a collaborative mindset is of vital importance to the success of any IOS. With blockchain, which is lacking central authorities to foster collaboration, this might become especially important [75][87].
- Developing a common understanding of rules and goals of the system is a challenge. Some participants could focus on personal or company incentives, instead of sharing and thinking about a global incentive for the network.
- Organizations are often afraid to give up control over their information resources, even if the benefits are clear. [57][69][75][85]. The fact that blockchain is completely decentralized increases this uncertainty as data privacy and security are also still up for debate [88].
- Trust pops up as an important determinant for blockchain and IOS success. The authors note that blockchain could cause a paradigm shift with regard to trust, shifting the perspective from trust in institutions to mostly trusting technology.
- Blockchain networks can benefit from network effects. Size and stability of the network are important. Convincing relevant partners to join the network can however be challenging.

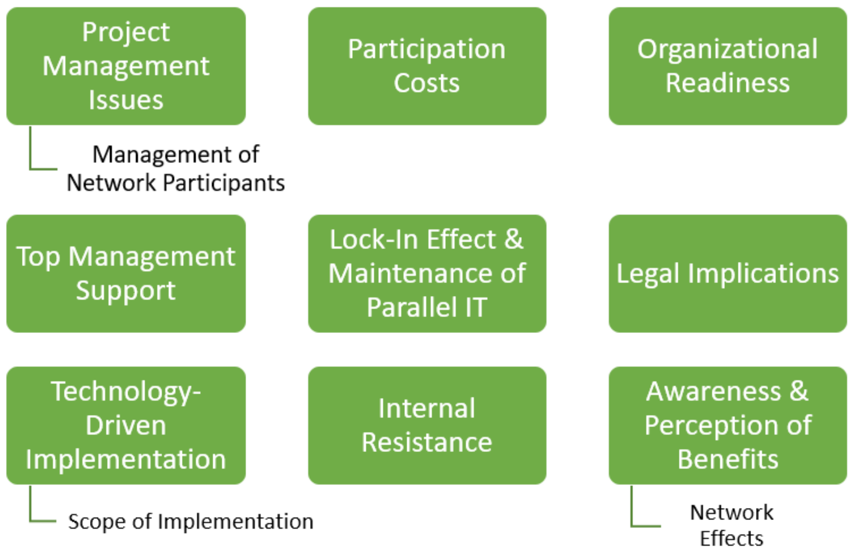

Figure 3.4: Organizational Barriers [75]

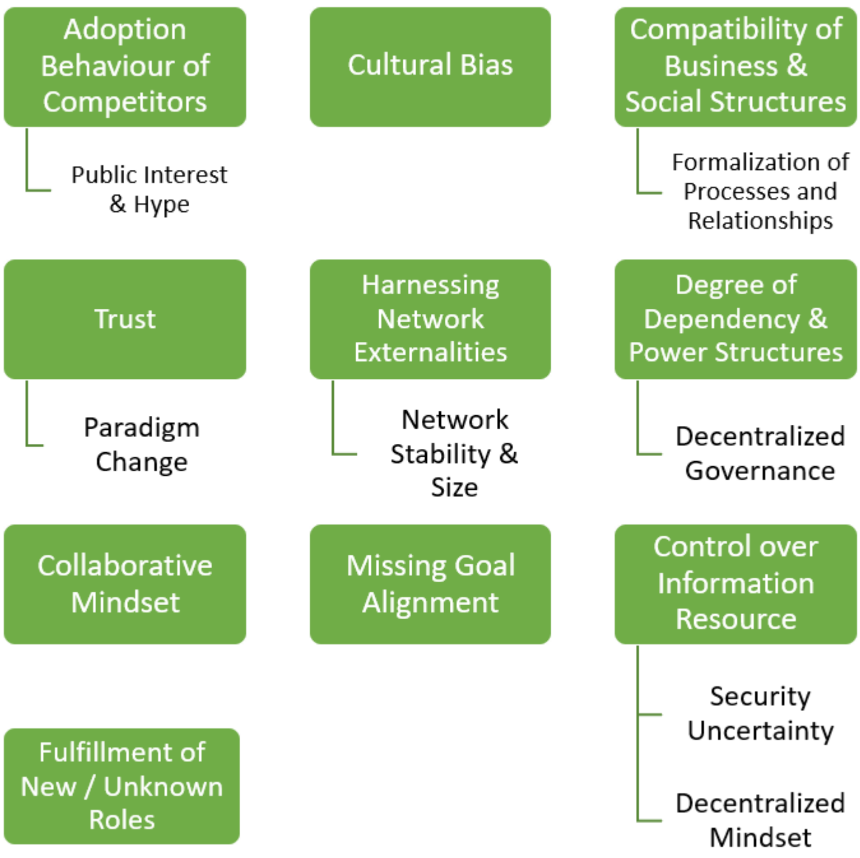

Figure 3.5: Network Barriers [75]

- Institutional pressures may negatively influence the implementation of IOS. Dominant companies can use their power position to force trading partners to join their IOS and to follow certain governance and design decisions. Decentralized governance is however still an open issue [89][90].

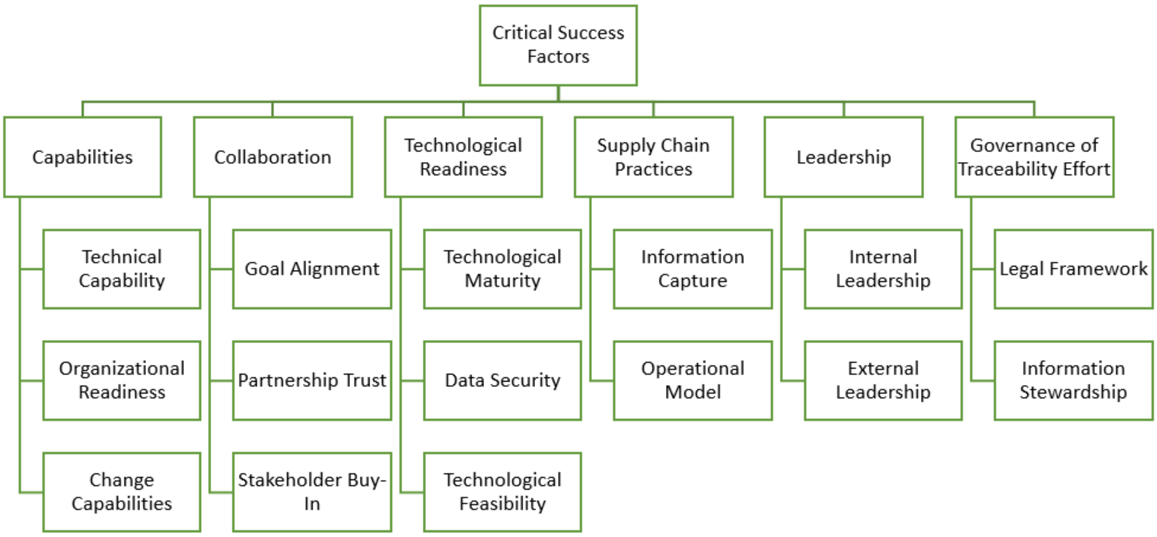

Figure 3.6: Critical Success Factors for Traceability Implementation [70]

- Another challenge is the concept of competitive pressure, referring to companies adopting a certain technology or practice, just because similar companies are getting involved. For blockchain, this is especially relevant given the public hype.
- The culture of a company may lead to routine rigidity preventing new collaboration mechanisms. Such institutional distance negatively impacts the development of mutual beliefs, goals or practices.
- Missing compatibility of business and social structures may lead to structural contradictions. There is often a lack of a common language or process understanding across organizations. This is required for process formalization which is necessary for the Turing-complete implementation of smart contracts.
- Finally Seebacher and Schüritz note a barrier not relevant for IOS, but to blockchain, which is that the initiators of a blockchain network might have to become the network orchestrator, a role they are not used to. This involves developing, growing and maintaining the network.

As a last framework, Hastig and Sodhi provided a framework of Critical Success Factors for the implementation of traceability systems in production systems [70], see Figure 3.6. These are:

- Capabilities
- Collaboration
- Technological Readiness
- Supply Chain Practices
- Leadership
- Governance of Traceability Effort

Comparing the framework of Hastig and Sodhi with the barriers of Seebacher and Schüritz, a lot of similarities can be found. There is a little difference as their viewpoint is distinct. Seebacher and Schüritz list barriers, while Hastig and Sodhi list critical success factors, indicating that these factors should suffice in tackling the major barriers to implementation. When this is recognized, almost all points are found in both frameworks. Through this it is established that a traceability system is, on a strategic level, just another interorganizational system and many of the issues impacting other technologies also apply to blockchain. The similarities also illustrate that it is hard to identify the true differences between traditional and blockchain technologies.

3.4. Key Points

Summing up this chapter, it has been found that modern supply chains can benefit from increased collaboration and information sharing. Blockchain has been shown to share a lot of similarities with other interorganizational systems, in terms of benefits and challenges, therefore somewhat reducing the perception of its uniqueness. The most mentioned use cases for blockchain in supply chains concern transparency, visibility and traceability, smart contracts and automation, and trust-building and collaboration.

It was also found that rather than establishing a trustless system with blockchain, it is more likely that the focus of trust will just shift, or that this trust in the actors will remain a part and requirement of the system as before. With regard to the challenges of implementation, they are generally grouped in technical, organizational and network-related challenges. Most of the challenges apply to any IOS, with some nuances or changes due to the characteristics of blockchain or relating to the relative novelty of the technology.

4

Food Supply Chains and Traceability

This chapter focuses on the food supply chain and its need for traceability, as these are the main industry and use case under investigation in this research. Literature provided in this chapter can add context to answer Research Questions 1 and 4 for the focal company in this research.

4.1. Characteristics

For the food supply chain, traceability is of great importance. Food safety and authenticity are always of concern. According to Aung and Chang [91] good traceability systems help to minimize the production and distribution of unsafe or poor quality products, thereby minimizing the potential for bad publicity, liability and recalls. The current food labelling system cannot guarantee that food is authentic, good quality and safe. They note that several technological developments can help to achieve farm-to-fork traceability, as the benefits of having a good traceability will far outweigh the costs [91]. The food industry has recently been faced with increased compliance regulations, stringent quality demands, more severe product recalls and growing concern with food fraud and ethical practices. All of these require more advanced traceability and visibility capabilities [92][93].

In general, two types of food supply chains (FSC) are distinguished [94]:

- Fresh Produce Supply Chains: In these supply chains, the intrinsic characteristics of the products remain untouched during all interactions with supply chain actors. These products include fresh vegetables, flowers and fruits.
- Processed Food Products Supply Chains are characterized by certain processes where agricultural products are used as raw materials for consumer products with higher added value.

Three different stakeholder groups can be defined which could play an enabling or blocking role in delivering food traceability: supply chain partners (ranging from producers to retailers), consumers and authorities or regulators, which have an interest in guaranteeing food safety by making laws and regulations.

Food supply chain traceability is challenging and influenced by sector-specific characteristics [95]:

- Supply chains consist of both continuous product flows (products traced in volumes) and discrete products flows (products traced in units)
- Batches have to be processed separately to prevent cross-contamination. This is hard in continuous flow operations.
- Diverging and converging product flows.
- High connected supply chains where waste products in one chain are inputs for other chains.
- Food products are often highly perishable, putting high demand from safety regulations and quality standards. Traceability information therefore contains a more rich set of data.

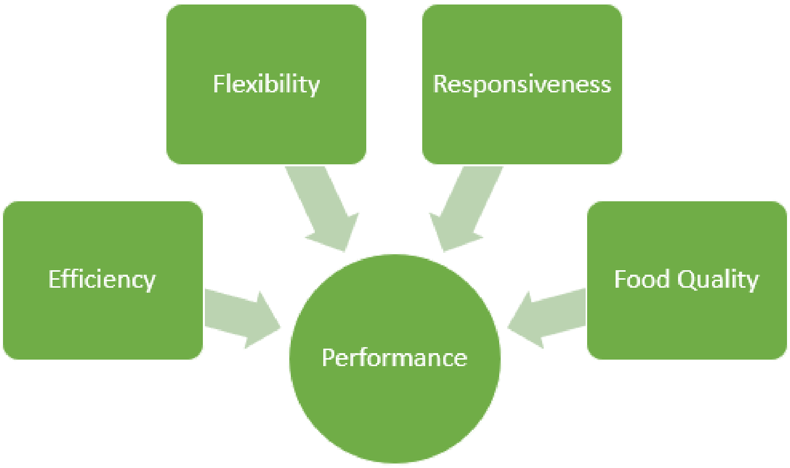

Figure 4.1: Categories for Key Performance Indicators in Food Supply Chains, based on [96].

- They are a complex network of many small- to medium-sized enterprises that interact with multinationals. They often span borders which makes tracking and tracing even more complex.

Aramyan et al. has defined the key performance indicators for agri-food supply chains in [96][97], see Figure 4.1. They are:

- Efficiency
  - Production and Distribution Cost, which is the combined cost of raw materials and labor in producing goods/combined costs of distribution, including transportation and handling.
  - Transaction Costs are the other costs rather than the money price that are incurred in trading good or services, like searching, negotiation, and enforcement costs.
  - Profit is the positive gain from an investment or business operations after subtracting all expenses.
  - Return on Investment (ROI) is a measure of a firm's profitability and measures how effectively the firm uses its capital to generate profit
  - Inventory, the firm's merchandise, raw material, and finished and unfinished products which have not yet been sold.
- Flexibility
  - Customer satisfaction is the degree to which customers are satisfied with the products or services.
  - Volume flexibility, the ability to change the output levels of the products produced.
  - Delivery flexibility is the ability to change planned delivery dates.
  - Backorders are orders that are currently not in stock, but are being re-ordered and will be available later.
  - Lost sales are those sales that are lost due to a stock out, because the customer is not willing to wait for a backorder.
- Responsiveness
  - Fill rate is the percentage of units ordered that are shipped on a given order.
  - Product lateness is the amount of time between the promised product delivery date and the actual product delivery date.

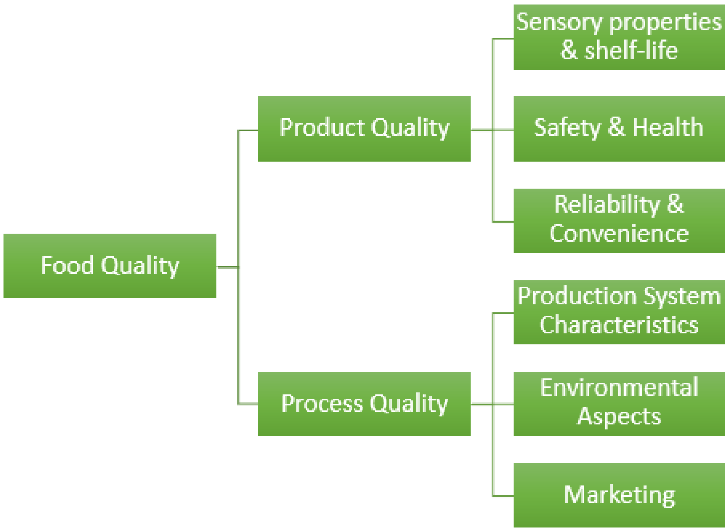

Figure 4.2: Food Quality Performance Indicators, based on [96]

- Customer response time is the amount of time between an order being made and its corresponding delivery.
- Lead time, the amount of time required to produce a particular item or service.
- Customer complaints are registered complaints from customers about a product or service.
- Shipping errors are wrong product shipments.

- Food Quality
  - Food Quality
    - Sensory Properties
      - Appearance, combination of different attributes on first sight.
      - Taste.
      - Shelf Life, the length of time packaged food will last without deteriorating.
    - Safety
      - Salubrity, the healthiness and nutritional value of products.
      - Product Safety, product does not exceed an acceptable level of risk associated with pathogenic organisms or chemical and physical hazards.
    - Reliability
      - Product Reliability refers to the compliance of the actual product composition with the product description. This can be measured by the amount of complaints.
      - Convenience is a measure of the information provided on the packaging for usefulness and completeness, can be measured by counting complaints.
  - Process Quality
    - Production System Characteristics
      - Traceability is the ability to trace the history, application or location of an product using recorded identifications. Can be measured by information availability, use of barcodes or standardization.
      - Storage and Transport Conditions are the standard conditions required for transportation and storage of the products that are optimal for good quality.
      - Working Conditions are the standard conditions that ensure hygienic and safe working environment with correct handling and good conditions.

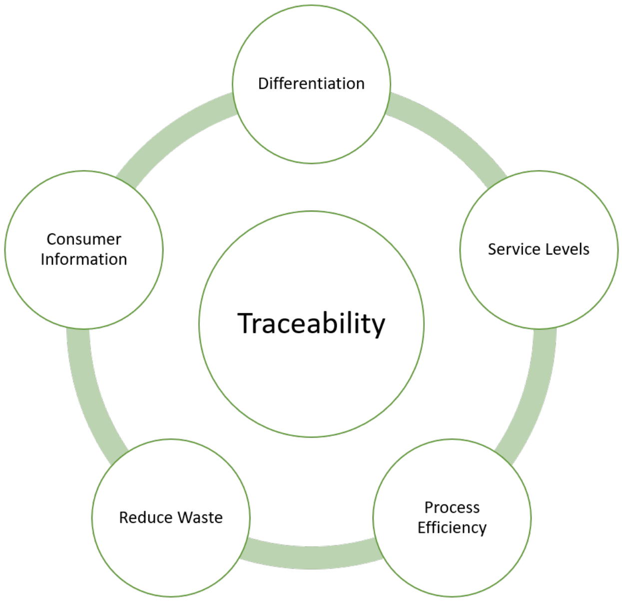

Figure 4.3: Traceability information applications based on [98]

- ⋄ Environmental Aspects
  - · Energy Use, the amount of energy used during the production process.
  - · Water Use, the amount of water used during the production process.
  - · Pesticide Use, a permitted amount of pesticides used in the production process.
  - · Recycling, collected used product that is disassembled, separated and processed into recycled products, components or materials.
- ⋄ Marketing
  - · Promotion, activities intended to increase market share for product (e.g. branding, pricing and labeling) measured by increase in number of sales.
  - · Customer Service is the provision of labor and other resources, for the purpose of increasing the value that buyers receive from their purchases and from the processes leading up to the purchase. Can be measured as the ratio of provision of resources used to increased sales.
  - · Display in stores: the demonstration of the product in stores.

Not all of these performance measures will be affected by improving traceability or visibility. Using the framework by Verdenius shown in Figure 4.3, there are five broadly defined categories to which the information gathered from traceability systems is applicable [98]. The first is differentiation, either on product, brand, taste or quality. Another reason can be to improve service levels, preventing out-of-stock situations, reducing throughput time and potentially attracting new customers. Process efficiency and waste reduction are closely related, traceability information can be used to make better production plannings, optimise logistics, manage waste, energy efficiency and overall chain management. Finally, traceability information can be used to substantiate product claims, often related to health, origin, ethics or environmental claims.

The basic idea of traceability is the possibility to track where a certain is located and to trace the history of that item, where *Tracking* is defined by Scholten et al. as the determination of the ongoing location of items during their way through the supply chain and *Tracing* is the ability to know the historical locations, the time spent at each location, record of ownership, packaging configurations and environmental storage conditions for a particular item [95]. Tracing aims at defining the composition of an item and the treatments that an item has received during the various stages of the product life cycle. Backward tracing is used to determine the source of problems of a defective item and forward tracing is used to determine locations of items that were produced using defective materials, for example in a product recall [95]. See Figure 4.4.

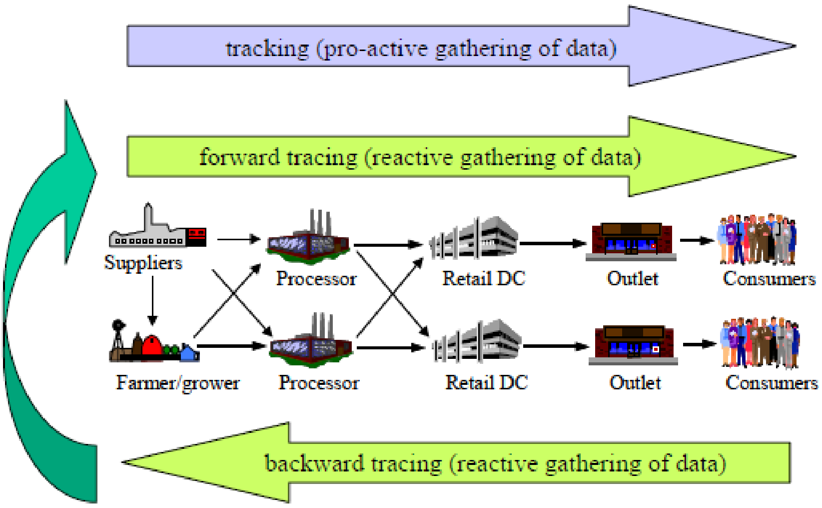

Figure 4.4: Tracking and Tracing in Food Supply Chains [94]

Scholten et al. distinguish two different architectures for food traceability systems, the *One-Step-Forward and One-Step-Back Approach* and an *Event-Oriented Approach* [95]. The first one complies to basic European regulations on traceability requirements that every partner should know where the products come from and where they go. Currently most companies rely on Electronic Data Interchange, labeling and paper trails to establish some kind of traceability. In this architecture, data follows the same path as the product, so every partner in the supply chain is also responsible for the collection, aggregation and handling of the data to the following partner. In a event-oriented approach all relevant events of food passing through a supply chain are logged in one or more repositories and make portals available for use by authorities, partners and or consumers.

4.2. Challenges

Traceability information should include transformation information and product information [99]. Transformations are points where resources are mixed, transferred, added and/or split-up. Product information covers properties relating to origin, processing history and location. The unique identification of traceable units and transformation recordings is often lacking [99]. A place where information loss occurs is called a critical traceability point (CTP) by Karlsen et al.[100]. Internal traceability is the ability to trace the product information internally in and has the following characteristics [99]: it is in one company, in one geographical location, has interfaces with production management systems, there a few privacy issues and is relatively easy. Chain traceability has the ability to trace the product information through links in a supply chain and has the following characteristics [99]: it occurs between companies and between countries, it depends on internal traceability being present, contains major privacy issues and standards are needed.

Behnke and Janssen [101] present the boundary conditions for a global traceability system using blockchain technology, in which they include both social and technical constraints. The boundary conditions, even the technical, are not exclusive to blockchain as a technology. Instead they assess what characteristics the system should have and if blockchain could fulfill the technical constraints. Their study has been done in the Dairy Sector. The eighteen boundary conditions found are shown in Figure 4.5.

Their collection of boundary conditions shows that in order to have a successful blockchain implementation for a use case, here traceability, it is much more important that the organization and underlying process are ready to share information and adhere to the same standards. They grouped the boundary conditions in five groups: Business, Supply Chain, Regulation, Quality and Traceability. Of the 18 conditions, only 5 offer a requirement for a technology solution implementing the traceability. This emphasizes the need to understand the specific context of the company and industry if traceability is a business demand, before deciding on a technology implementation. Also it is noticeable that almost all boundary conditions mention that some kind of standardization needs to happen, on a quality,

No.	Category	Boundary condition
1	Business	Actors in the supply chain have standardized the traceable resource units which are used for internal and external traceability of products
2	Business	Product and process properties (traceability data) are recorded
3	Business	Actors in the supply chain are technologically capable to have access to the traceability information system
4	Business	Data from the traceability system are mapped to internal processes in order to be able to maintain internal traceability
5	Business	Business requirements are consistent and make no difference between internal or external supplier.
6	Business	Confidentiality requirements apply with respect to the transparency of actors in the supply chain.
7	Supply Chain	Standardization of quality requirements between all actors in the supply chain
8	Supply Chain	Same quality standards apply for the internal supply chain process as for the external supply chain process
9	Supply Chain	Interfaces with customers and suppliers are generic enough to support customized production processes
10	Regulation	Compliance of all actors in the supply chain with FSSC 22,000
11	Regulation	Compliance with special quality requirements for products
12	Regulation	Compliance with country-specific / customer-specific requirements
13	Quality	Consistency between the actors in the supply chain on type, format and level of details of quality information (master data)
14	Quality	Support for the level of details of quality data and data about origin of ingredient to consumer by all actors in the supply chain
15	Traceability	Consensus between the actors in the supply chain on type of traceability data
16	Traceability	Standard about the level of detail of traceability information required to store critical traceability points
17	Traceability	Granularity of internal traceability is in line with traceability goals across the supply chain and supported by all actors
18	Traceability	Standardization of internal processes with respect to critical traceability points and traceability data

Figure 4.5: Boundary conditions for a food traceability system [101]

compliance or data level.

Therefore critical to the development of traceability systems are enabling technologies and standards. Scholten et al. list three different technology groups that could help: Automatic Identification and Data Capture (AIDC), connectivity technology and business intelligence systems. To make sure information between organizations is exchanged in an efficient and error-free way, it is vital that supply chain partners speak the same language, that is, data standards apply that make interoperability possible [95]. This includes format, content and communication methods. Verdouw lists the most important supply chain information standards as [102]:

- Identification Standards: Codes that are used as information keys in applications throughout the entire chain, like scanning bar codes, reading RFID tags. In food supply chains identification standards of GS1 are broadly adopted. The GS1 includes standards for different levels of granularity, of which it recognizes four: shipment unit, logistic units, trade units and consumer units [103].

- Auto-ID standards: Agreements about the size of bar codes, RFID chips etc, so they can be read consistently.

- Data Communication Standards: Technical agreements about how information should be exchanged between parties.

- Standard Messages: Agreements on the functionality and structure of the electronic messages and what information to include.

4.3. Blockchain

Blockchain is an innovation in the group of business intelligence systems, playing a role in enabling advanced traceability systems. Several authors note the applicability of blockchain in food supply chains. Tian discuss the combination of RFID and blockchain, where he notes the benefits to transparency for the whole market, the improved credibility of the industry and fighting counterfeit products. These conclusions are similar to those made by [105] for the wine industry and [106] for agriculture. Kamilaris et al. lists the benefits of blockchain to be providing a secure way to perform transactions among different untrusted parties, and traceability with a decentralized ledger helps to connect inputs that are far apart or distinct in other ways [107]. It lists the common benefits to traceability as quality assurance and sustainability, but it also notes the upside for usage in the developing world, especially for small farmer cooperations, by increasing transparency, establishing traceability, quantifying physical assets on the blockchain and providing access financial instruments [107][108].

To illustrate how this works, some examples of blockchain pilots in the food supply chain are described below. This is not an exhaustive set, but merely an indication of famous examples.

Container Tracking - Maersk and IBM

The container tracking pilots of Maersk and IBM are some of the most well known proof-of-concepts delivered until today. Maersk, a Danish shipping multinational, had been looking for a better way to trace the goods it ships. The key problem involved for Maersk was the incredible amount of paperwork related to international shipping. IBM and Maersk together developed a blockchain solution, based on Hyperledger Fabric, which would allow customs authorities, after signing a document, to upload a digital copy to the blockchain. This way all parties were always up-to-date on the status of a shipment and if conflict evolved later, they could always go back to the same document and see that it had not been altered. The first pilot in 2014 tracked a shipment of avocados and roses from East Africa to Europe. They found that many costly delays are caused by missing paperwork and to finish a customs procedure would involve over 200 different interactions. Also in global shipping, fraud is common. The bill of lading is often tampered with, goods are taken from containers or counterfeit products are included in the shipments. The pilot was considered a success and has potential to save up to 15% of cargo value.

Provenance - Tuna Tracking

Provenance is a small tech social enterprise, building traceability solutions on blockchain. It is quite well known and its most famous demonstration has been tracking the sustainable catch of tuna in Indonesia [109].

They establish that there is no single organization that can be made responsible for making data throughout the whole supply chain transparent. They also noted that all companies they interviewed using pen and paper accounting for their material flow.

First step in the system was the onboarding of fishermen. Social and environmental conditions were verified by local NGO's, making the fishermen eligible to participate on the platform. Then their ID on the blockchain would be added with relevant attributes (certificates, GPS).

When a fishermen made a catch and wanted to sell it to a supplier, he/she would send a SMS message to the system registering their catch, creating a new asset on the blockchain. Accompanied by their own unique ID, both the physical and digital ownership would then be transferred to the supplier.

Inside the factory where the raw fish would be processed into separate cans of tuna, they make use of an external system to check the integrity of the product. This is done by a concept of mass balancing, where the output (in weight) should equal the input of certified tuna plus additives.

The system works on top of existing ERP or other data management systems, with the opportunity to share data between factories and deliver visibility from first mile to end consumer.

Pork and Mango Tracking - Walmart and IBM

In response to food contamination scandals, Walmart wanted to increase its food safety practices. Together with IBM, they piloted blockchain solutions to track the food supply chain. One pilot was tracking pork in China, the other one mangoes from Latin America [57][110].

The pigs where smart tagged with barcodes and also followed by cameras in the pens and slaughterhouses. It also used already available sensors in shipping trucks to monitor the condition and location of the pork in transit.

In the concurrent mango pilot, Walmart and IBM tracked sliced mangoes from South/Central America to North America. Mangoes shipped worldwide are susceptible to bacteria contaminations, therefore Walmart needed to demonstrate transferability and accountability across borders. They stored information about farm origination, batch numbers, processing data, soil quality and fertilizers, storage temperatures and shipping data. The pilot reported a reduction time in origin tracking from several days to 2.2 seconds.

One of the success factors Walmart mentions themselves is early involvement of stakeholders, especially necessary government agencies who could support the project. Next to that they were involved in designing the system architecture and integration with enterprise systems, while leaving the programming of the chaincode to IBM. Also they worked with relevant standard organizations (GS1) to define data attributes for blockchain.

It now tracks 25 products from 5 different suppliers using blockchain. It intends to scale up and will require suppliers of certain products to adopt the new system, which requires new labeling [111].

Bumblauskas et al. [93] write about a proof-of-concept created with an American egg packer wanting to give the consumer insight in where his eggs came from. They build a system on Hyperledger Sawtooth and custom smart contracts. Next to that also extra custom software and hardware was developed including API, client interfaces and IoT sensors. The system captured data at specific farms from both custom sensors as third party sensors. Then at the plant the system relied on internal traceability software, processing hardware and data entry from system operators [93]

Comparison Blockchain and Conventional Systems

As shown in the preceding sections, a lot has been written about the potential for blockchain applications within supply chain, most often combined with traceability use cases. Blockchain is supposed to be prevent counterfeit products, decrease the effect of product recalls, improve sustainability performance and increase operational efficiency [58]. While these aspects all hold some truths, it is not very often discussed in literature when a blockchain approach is more appropriate for a certain use case than a traditional traceability system.

Olsen et al. did try to make a comparison between functionality of traditional traceability systems versus blockchain-enabled ones [112]. They also note the vast amount of blockchain implementations, as shown in Chapter 2, and the implications this have for performance characteristics. They state that fundamentally the real difference between blockchain and traditional (relational databases) traceability system is the underlying data structure. This has as a consequence that inherent differences do exist, but that these are related to the immutable nature of the blockchain data structure.

Their main critique of blockchain literature is that blockchain implementations are not compared to non-blockchain implementations, but for instance online implementations are compared with offline or distributed against centralised systems. They note that blockchain pilots often are not tested in the same environment as non-blockchain systems and that other adjustments to the testing environment have been made in order for the system to function. As an example, they provide the often stated value of reduction of the trace time of mangoes from six days to a few seconds. This incredible gain is not attributable to the data structure, but to the change of fragmented, non-integrated, manual data to online, distributed and connected data.

Olsen et al. think it is better to analyse the attributes and implementation options separately and indicate pros and cons of each. They compare traditional, electronic traceability systems and electronic blockchain traceability systems on eight criteria.

- *Suitability of Database*: Traditional systems record state variables, where blockchain systems records transactions, making it well suited for transformations of products.
- *Data quality and veracity*: In both cases data providers must check and vouch for data quality and the systems suffer from the ”Garbage In, Garbage Out” principle, but with blockchain the chances of getting caught are higher, making it less likely to occur.
- *Immutability, integrity, and transparency*: In traditional systems, data elements can be overwritten, although version logs do exist. They give the example of a feed silo where in a traditional setup, the storage level would be a (claimed) variable, in a blockchain setup, the storage level is a derived variable calculated from processing all transactions. Therefore blockchains systems have a higher degree of transparency and integrity.
- *Confidentiality*: Blockchain technology was not designed for confidentiality. Although modern private blockchain implementations provide a lot more confidentiality than Satoshi Nakomoto had ever foreseen, by design blockchain provides transparency, which is to some degree mutually exclusive with confidentiality. Data access and confidentiality is often designed externally and ad-hoc.
- *Trust*: They state that blockchain systems do not provide any disadvantages in relation to trust, but the fact that the data becomes more trustworthy does not replace the fact that suppliers still need to be trusted to deliver high quality and safe products. Therefore with respect to this, the impact is not as profound as sometimes claimed.
- *Robustness*: Redundancy is inherent to blockchain, where many copies of the database exist and state values can be traced by recalculating the transactions. Redundancy can also be implemented in a traditional setting, but it is harder to completely seal of the impact of hacks and incidents.

Comparison criteria	Traditional electronic traceability system	Electronic traceability system based on blockchain technology
Suitability of database	Records (claimed) variable states, versatile	Records transactions, well suited for recording transformations
Data Quality and Veracity	Data provider must check and vouch for data quality and veracity	Data provider must check and vouch for data quality and veracity, but fraud frequency may be lower as risk of getting caught is higher
Immutability integrity and transparency	Data elements can be overwritten; needs additional recording (transaction log or similar) to document this	Only the transactions are recorded, which means a higher level of integrity and transparency of the claimed values
Confidentiality	Easy to integrate tiered levels of access	Can be done but to some degree it goes against the philosophy of what a blockchain implementation is meant to support.
Trust	Based on trust in the food business and the brand	Still based on trust in the food business and the brand but trust may be higher because of higher degree of data integrity and transparency
Robustness	Duplication and other means of providing robustness must be provided by external processes	Robustness and duplication of data is built into the system
Speed and efficiency	As good as you can get	Significant overhead related to duplication, error checking, consensus mechanisms and calculating the state of variables based on
Interoperability	There is a plethora of systems implementations and database structures. There are competing standards for TRU identification and EDI. And there are very few standards defining how the recorded data elements should be named and measured. This means that system interoperability (exchange of data) is a big problem.	Blockchain-based systems are less diverse; they all record transactions (transformations) rather than state values and they are all immutable. Interoperability and data interchange between blockchain-based food traceability systems is easier than between existing systems any many of the success stories reported is because a higher degree of interoperability has been achieved.

Figure 4.6: Comparison between traditional and blockchain-enabled electronic traceability systems, derived from [112].

- *Speed and Efficiency*: The extra integrity of blockchain comes at a cost. Blockchain systems have to do more operations to process a transaction and the redundancy also makes the process more efficient than comparable conventional system setups.
- *Interoperability*: They state that blockchain systems are a lot more homogeneous, just because there are so much more implementation options and structures for traditional traceability systems. To increase interoperability for conventional systems would require the creation and widespread adoption of more advanced standards for both electronic data interchange and data content. Currently different standard exist, which makes interoperability low. Thus interoperability is not higher due to any of the blockchain characteristics, but purely related to the state of development of the technology.

They summarize that based on these criteria, blockchain-enabled traceability systems might have the upper hand when deciding between the two options. Traditional systems benefit from the better speed and efficiency and to some degree better confidentiality options. Blockchains systems currently clearly win on interoperability and provide advantages on the other points, see Figure 4.6.

4.4. Measurement

In the context of this research, the traceability performance indicator from [97] could be more extensive. Caridi et al. have written about measuring supply chain visibility metric and developed an overall measure for this. They identify to be important both the quantity of exchanged information (i.e. the number of transactions/events, status information, master data and operational plans that the focal company has access to) and the quality of the information [113]. This quality has two dimensions: freshness, the degree of information synchronisation with business partners and accuracy, the degree of conformity of the shared information with its actual value.

These three metrics are semi-quantative judgments given by supply chain managers. Quantity and quality judgments are collected for each type of information flow (transactions, status information, master data and operational plans).

The contribution of each node (a supply chain partner) in a supply chain is weighted on the basis of three criteria:

- Localization: the distance of each node from the supply chain leader both in terms of the number of tiers between the node and the focal company and in terms of its vertical integration, where first tier suppliers are considered more critical than Tier-2 and so on, $Wloc_k$ which is calculated with the following formula.

$$\text{wloc}_k = \begin{cases} 1 & \text{for first-tier suppliers} \\ 1 - \frac{\sum_{n \in I_k} \text{AV}_n}{S_{m,\text{FC}}} & \text{for suppliers belonging to tier } z, \text{ with } z \geq 2 \end{cases}$$

, where I_k is the set of nodes belonging to the path k from the focal company, n is a node beloning to I_k, AV_n is the added value of node n, m is the first tier node beloning to I_k and $S_{m,FC}$ is the volume of sales from the node m to the focal company FC.

- Significance: the more the focal company buys from a supplier, the more interested the focal company should be in having visibility in this supplier. The significance for first tier node is:

$$\text{wsig}_k = \frac{S_{k,\text{FC}}}{\sum_{n \in Z_1} S_{n,\text{FC}}}$$

and for upstream nodes, the significance of a node k belonging to tier z is:

$$\text{wsig}_k = \frac{S_{k,m}}{\sum_{i \in Z_z} S_{i,m}} * \text{wsig}_m$$

- Criticality: a measure established by Kraljic [114] to describe the criticality of a certain component from a strategic purchasing perspective. Caridi et al. use a four point scale for the four categories on the Kraljic matrix [113]. Kraljic defines non-critical items, which are easily substituted and have a large supplier base, *leverage items*, which are critical to the end product, but also has plenty of suppliers, *bottleneck items*, which are non-critical, but have few supplier and *strategic items* which are both critical and have few suppliers. They are awarded a score from 1 to 4 in this order.

The weight is then calculated as $\sqrt{(wloc * wsig)}$, except when the criticality is low (non-strategic and leverage items) and the result of the calculation is low and below a certain threshold, indicating that the node is either very distant or the amount of goods exchanged is very low.

Asioli et al. proposes a model of traceability performance using three parameters: breadth, depth and precision [115]. Breadth is defined as describing the amount of information collected that can be connected to the lot, similar to the quantity parameter of [113]. Depth describes how far back or forward the system regularly traces the relevant information, which is slightly different to [113], as they use localization to make further away suppliers less important, although the Criticality parameter compensates for this. The last parameter precision reflects the size of a traceable lot or batch that is uniquely identified, sometimes referred to as granularity.

Bosona and Gebresenbet also come up with similar parameters. They list the following four: breadth, depth, precision and access, where access is defined as the speed with which tracking and tracing information can be communicated to supply chain members when necessary.

4.5. Key Points

The information in this chapter has added an extra layer to the literature presented in the previous chapters. From the general characteristics of food supply chain, it was illustrated that traceability is by default more difficult due to the inherent nature of its processes involving product mixing, the complexity of product streams and the demanding food regulations. Three technological groups were identified which are necessary to overcome the challenges of traceability in food supply chains: automatic identification and data capture, connectivity and business intelligence systems. A lot of sources connect blockchain, as an example of business intelligence system, with another technology to establish traceability, often RFID/IoT technology. Those examples choose blockchain for its transparency and ability to connect decentralized, untrusted parties, which is typical for global food supply chains.

Few sources, using blockchain, are specific on the benefits it provides in contrast to traditional, centralized systems. The discovered advantages for centralized systems were confidentiality and efficiency, while blockchain had an advantage on data quality, transparency, trust, robustness and interoperability, but this knowledge base is limited.

5

The HEINEKEN Company

This chapter introduces the focal company of this research, The HEINEKEN Company. It provides background to some of the information assumed known in the interviews and presents the specific supply chains of the experts interviewed during this research.

5.1. General Information

Heineken is a Dutch brewing company founded in 1864. Starting as a single brewery in Amsterdam, Heineken International NV is now the largest brewer in Europe and brews over 300 international, regional, local and speciality beers and ciders. They operate 167 breweries worldwide and sell to consumers in over 190 countries. Heineken is now the second largest brewing company in the world with a total production volume of 241.4 million hectoliters of beer in 2019, the Heineken brand is almost 25% of this volume. Worldwide it employs over 85.000 people, generating almost 24 billion euros of net revenue and 2.5 billion in profit [117].

The Heineken Group consists of Heineken Holding N.V. and Heineken N.V.. Heineken Holding is majority owned by L'Arche Green N.V. which is almost completely owned by the Heineken family. The other parts are owned by public shareholders and FEMSA, a Mexican multinational in the beverage industry. The object of Heineken Holding N.V. is to manage or supervise the management of the Heineken group and provide services for Heineken N.V.. It does not engage in any operational activities itself. It assigned this to Heineken N.V. and its subsidiaries and associated companies. Its only income stems from dividends received [118].

The Heineken Holding owns a majority share in Heineken N.V. making sure the Heineken family is still in charge. Again the remaining shares are owned by public shareholders or FEMSA, see Figure 5.1 for the exact numbers. Heineken N.V. (hereafter referred to as Heineken) operates through its executive board in charge of setting global agendas for their functions and steering the direction of Regional Management and Global Departments. The regional management is divided into four regions: Europe, Asia Pacific, the Americas and Africa, Middle East and Eastern Europe. The national operational activities are managed by individual operating companies (OpCo), which often stems from direct acquisitions of local brands and still enjoy a large share of autonomy. The Global Departments set out guidelines and principles in ways-of-working that all Heineken brands should adhere to, but the OpCo's can launch individual marketing or sales campaigns, decide on distribution strategies etc.

The case study is with Heineken, the international beer brewer. In this chapter, background information on the company and on food supply chain traceability is given.

5.2. Value Chain

The Heineken value chain is long and global. The exact make up of ingredients and processes differs between brands and regions, but the beer brewing/selling process can be generalized into seven steps: Agriculture, Malting, Brewing, Packaging, Distribution, Customer and Consumer, see Figure 5.2.

The vast majority of beers are made from just four ingredients. The process takes malted barley, hops and water, and combines these with yeast. Through fermentation lager is created.

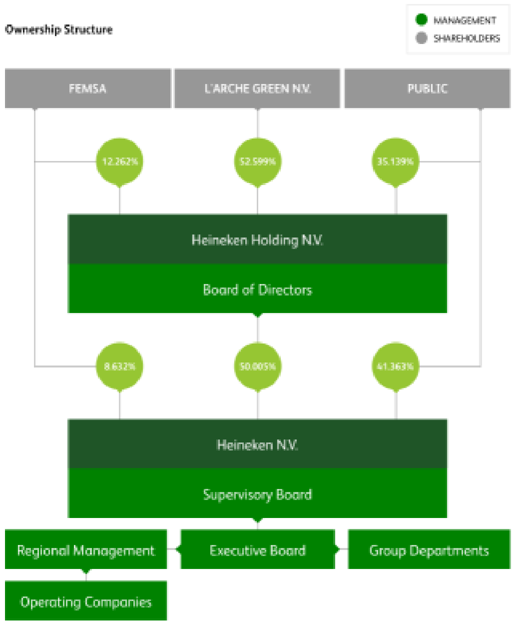

Figure 5.1: Heineken Ownership Structure [119]

Figure 5.2: Heineken Value Chain

Agriculture and Malting

Heineken is the owner of the brewing process, but for its raw materials it relies fully on its external suppliers. Barley and hops are the main raw materials for lager, but also for the other products like cider, Heineken sources apples, maize, rice, sorghum, sugar and apple juice concentrate. The volumes are large, for example Heineken uses 1.3% of all the grain harvested globally and use 33% of all British apples for their ciders.

Sustainability is a big concern here. Heineken works together with farmers to improve crop yields and overall quality. They have also stated the want to increase their usage of sustainable sources, in both an environmentally and socially responsible way.

Heineken owns several malteries, but it also buys malt from third parties. The malting process consumes a lot of energy and water and requires transportation.

Brewing Process

The process starts with barley which is a grain containing fibres, protein and starch. It is soaked to start the germination process. This releases the enzymes that unlock the grain. After soaking the barley is heated to dry out over the course of a few days. This step is called malting. During malting, the starch in the barley is converted into sugars which will eventually become the alcohol.

Next water is mixed with the crushed and malted barley. This creates wort, a sweet sugary liquid, which is then boiled. Up to 95% of the end product can consist of water, so the quality of the water is

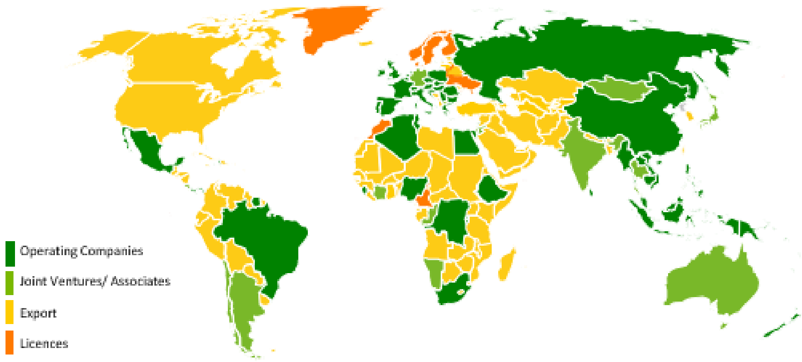

Figure 5.3: Heineken Global Presence

an important factor in the quality of the end product.

The following step concerns the hops. Hops give lager its bitterness and can also contribute to the aroma. There are many varieties of hops, each with a distinctive flavour. The choice of hops therefore influences the taste of the beer. The hops are added to the boiling water.

The last step of brewing beer is adding yeast to the wort. This is done when the wort has cooled down. Different yeast strains produce different tastes. They are a major influence on the taste. Therefore the exact type of yeast is often kept secret. The four ingredients together then enter the process of fermentation, where the natural sugars are converted into alcohol and CO_2.

Packaging

After the brewing process, the beer needs to be bottled and packaged. The main package varieties are cans, bottles and kegs. To do this, it needs to source glass, metals and paper. Sustainable production practices from suppliers and increasing use of recycled materials is a priority for Heineken.

Distribution

Products are sold locally or exported around the world. The responsibility of export in Heineken is given to the Export Organisation Heineken Brouwerijen B.V., divided over four regions (AMEE (Africa-Middle East-Eurasia), Americas and EE&GDF (Export Europe & Global Duty Free)) and HAPE (Asia Pacific), see Figure 5.3. Depending on the brand and product, the product is shipped using multiple modes of transportation and on different scales. It mainly depends on the modes road, rail and water, using both ocean freight and inland shipping.

Customer & Consumer

Heineken does not sell its product to the end consumer. Again depending on brand and region, it will most often go through local operating companies which in turn often rely on third party distributors to get the product to the consumer.

5.3. Sustainability

Heineken has defined a clear and expansive strategy around sustainability in its *Brewing a Better World* program [117]. Here it lists six goals to contribute to a combined six UN Sustainable Development Goals, see Figure 5.4:

- **Advocating Responsible Consumption**: promoting moderate drinking behaviour through marketing and partnerships.
- **Promoting Health and Safety**: providing a safe work environment and to avoid harm to people.
- **Every Drop - Protecting Water Resources**: focusing on reducing water use in production and investing in wastewater treatment plants to preserve natural water reserves.
- **Drop the C - Reducing CO_2 Emissions**: The carbon footprint needs to be reduced across the entire business.

Figure 5.4: Brewing a Better World Program Goals [117]

- **Growing with Communities**: making a contribution to local communities by providing jobs and investing in social and economic well-being.
- **Sourcing Sustainably**: aiming to develop sustainable agricultural supply chains to increase the volume of sustainable raw materials

5.4. Upstream Supply Chains

Ten interviews have been carried out with Heineken experts to learn more about their capabilities and needs in terms of product traceability. The participants worked in different departments within Heineken, giving a broad and more accurate picture of the beliefs in the company. As this research has the Global Procurement Office as a basis, the emphasis is on roles around procurement functions. Three interviewees worked within Heineken Global Information Systems (GIS), where two interviewees were responsible specifically for procurement technology, while the other was more a generalist. Two participants were based in their local operating companies, Heineken Spain and Heineken Netherlands, and focused on customer service.

Five interviews were conducted with Global Category Leads in Heineken Global Procurement. Figure 5.5 represent their organizational structure for all (material) sourcing. Two participants were in the Raw Materials group, namely for Malt & Adjuncts and for Sugar & Glucoses. Two others were in the Packaging branch, including the categories Metal and Paper. The last one was in the Supply Chain department in Sustainable Product Services, which includes Chemicals and Adhesives.

The final interview was conducted with someone in the Heineken Global Supply Chain organization with a Global Quality Manager for Packaging materials.

Originally the interviews intended to focus on the boundary conditions and challenges of traceability primarily. However almost without exception, every participant in the interviews devoted significant amounts of times during interviews addressing the business case of traceability. Throughout the interviews, more concrete questions have therefore been asked about that to explore that topic further.

Malt & Adjuncts

One of the main ingredients of beer is barley. Barley is a cereal grain grown around the world. Before it is used for brewing, it is usually malted. Malting is a controlled germination process that converts raw grain into malt by soaking it with water and then drying it with hot air. Malt determines the colour of the

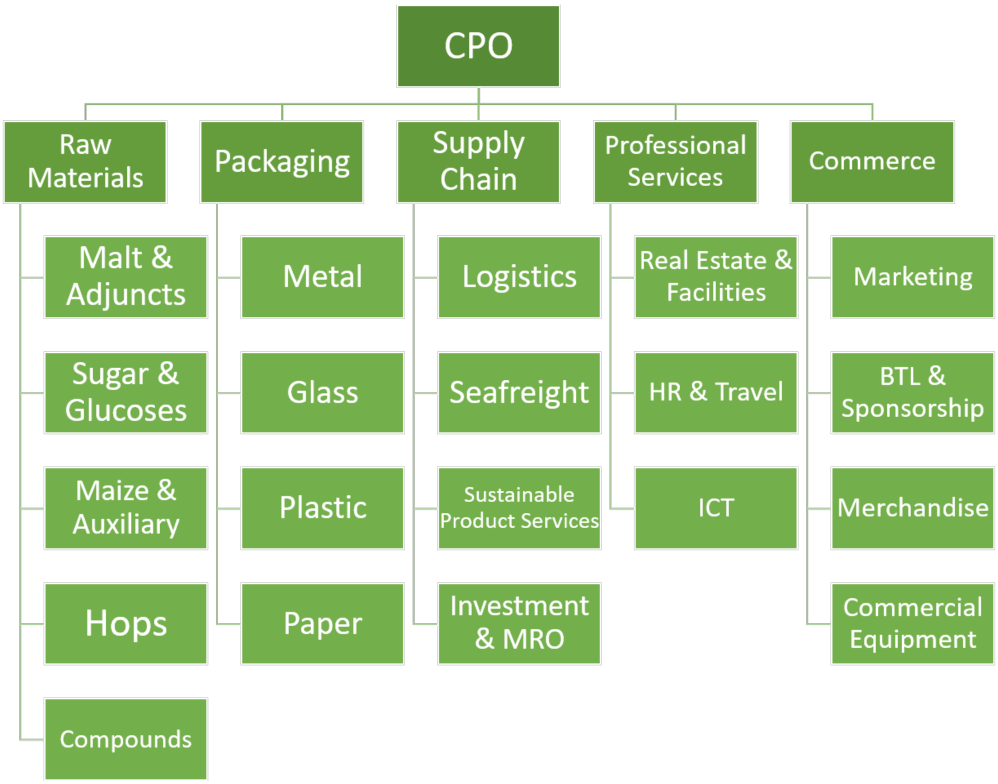

Figure 5.5: Heineken Global Procurement Sourcing Organogram

beer and releases the sugars which will be eventually converted to alcohol. For a Heineken pilsener the main grain for malting is barley, but also sorghum, wheat and rye can be used for instance. The malt supply chain can be seen in Figure 5.6. Farmers grow barley on their fields. As barley is an agricultural crop, production is limited to the crop cycles. Note that seed production can be also viewed as part of this supply chain as the seeds are the input for the farmers to grow their grains.

Farmers are often organized in cooperation or supported by merchants, which sells the raw material on the open commodity market. This means the price is fluctuating throughout the year depending on market and production conditions.

Figure 5.6: Malt Supply Chain

The grains are bought by maltsters which are responsible for the malting process. There are numerous maltsters in the market, but Heineken also has some inhouse malting facilities. About 25% of the malt used in Heineken is produced by inhouse maltsters, the biggest ones are in Belgium and Mexico. Looking at the sourced malts and including both pale malt, which is used in regular beer, and specialty malts, Heineken has about 80 - 90 suppliers for its malts and adjuncts.

Sweeteners & Starches

The category of sweeteners and starches consists mainly of sugars and sugar-derivatives. These products are used for three general applications: (1) sweetening of the products, (2) fermentation, where Heineken is looking to replace some of the four core ingredients of beer with cheaper or more efficient alternatives and (3) colouring, where mainly caramel is used to give a product a certain colour.

Sugar is a commodity product, it is traded on public markets. About 80% of the world's sugar production is done from sugar cane, with the remaining 20% coming from primarily sugar beets. What

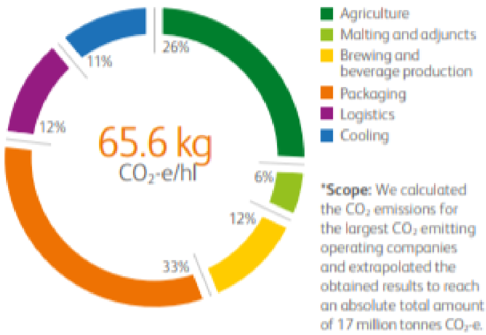

Figure 5.7: Heineken Product Carbon Footprint

kind of sugar is produced is a geographical issue, as sugar cane and sugar beets do not usually grow in the same geographical areas. The world market for sugar is dominated by Brazil and India, but sugar is produced worldwide in a variety of geographical areas and climates.

The price of sugar fluctuates by supply and demand and is therefore depended on crop yields and weather conditions, new demands for sugar (for instance, for the production of ethanol) and governmental policies.

Other important products include the derivatives of sugars and grains, for instance starch, glucose or fructose. Key characteristic for this category is that the products are all basically different parts of a carbonchain, which occur naturally, but not in the quantities demanded by Heineken. Therefore all of the raw materials bought by this category are already processed materials.

Which product is sourced depends on the application and the location. The buyers get the application, which is sweetening, fermentation or colouring and then find the product that achieves this goal in the local area. The chosen product is often the one that is either the cheapest or available in the largest quantities.

Metal

Heineken sources metal to package its products in certain ways. The most common uses for metal in Heineken packaging are aluminium cans and bottle caps. The interviewees talked mainly about the aluminum cans as they had concrete ideas of extending their current traceability capabilities in this regards. This interest is sparked by a demand for more sustainable material sourcing, outlined by the current corporate strategy [117]. Packaging is the biggest contributor in terms of CO_2 emissions per hectoliter of product produced, see also the pie chart in Figure 5.7. Packaging is responsible for 33% of the emissions, followed closely by raw materials (26%) and malting, brewing / production, logistics and cooling at a distance. Within the packaging group metal and glass represent both the biggest spend and CO_2 footprint. Therefore the buyers are interested in finding ways to reduce their contribution to the product footprint.

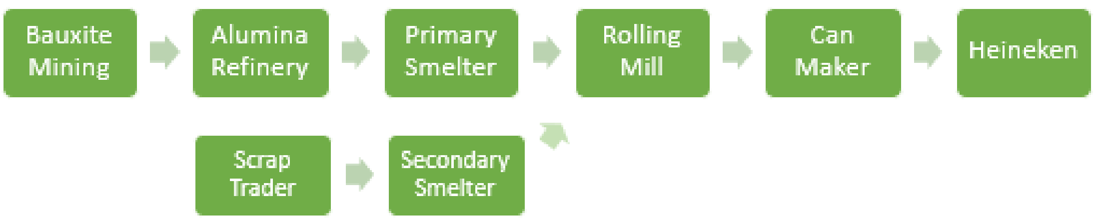

Figure 5.8: Aluminium Can Supply Chain

The beverage can supply chain is depicted in Figure 5.8. Heineken cans, like most beverage cans, are made of aluminium for 98% [120]. Aluminium is produced from bauxite ore, which is mined in

Figure 5.9: Paper Packaging Supply Chain

different parts of the world. This ore is then refined in a chemical process to aluminium powder and smelted down to pure aluminium. This aluminium is the input to rolling mills, which transform the aluminium into a coil with the appropriate characteristics to be usable in production for the can makers. The can makers then ultimately deliver the finished product to Heineken to be filled.

Paper

Heineken also packages some of its products with paper-based packaging materials. The so-called wrap-arounds hold the products together in a convenient way, like the small baskets that hold a six-pack of bottles. The paper industry is a worldwide industry with numerous players and high demands. Heineken Global Procurement sources from around 150 different suppliers on a global scale, but local operating companies also make use of an unknown amount of local suppliers, but this is a minority.

The supply chain of paper packaging materials can be seen in Figure 5.9. From different woodlands, trees are cut down and converted into logs. These logs serve as input to chip and pulp mills which produce the raw materials for the paper mills, the paper pulp. The paper mills use this pulp to make paper, which they produce on large rolls. These rolls are shipped to converters which produce the final packaging materials, so they take care of printing, folding etcetera. These products can be fed straight into Heineken's packaging lines, ready to be filled.

One of the key strategic points for this category is to reach the goal of using 100% certified paper. Two paper certifications exist that are of importance, FSC and PEFC. These certifications are given out by different organizations, but their goal is the same, protecting and ensuring sustainable forestry. Currently, Heineken Global sources around 90% certified paper.

Chemicals & Adhesives

Chemicals and adhesives are bought for various applications within Heineken. This group falls in the Sustainable Product Services category of the Supply Chain branch within HGP. This separation from raw materials indicate that these chemicals should not have direct contact with the consumer end products. The chemicals are both used for cleaning purposes (of the brewery production units) and in the Heineken laboratories. The other item in this category are adhesives, which are used for the glue in for instance the bottle labels. These did not come up a lot during the interviews, due to the interviewee's relative lack of experience with the products and suppliers.

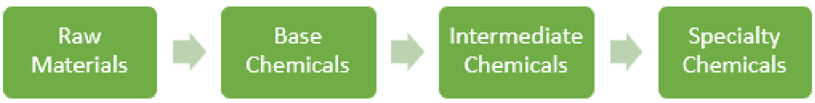

Figure 5.10: Chemicals Supply Chain (Based on [121])

Contracting for tenders is done on a global scale, but suppliers often have regional or local locations where they can ship from. In the end, Heineken sources from only a handful of suppliers. Although the applications are the same, there are regional differences in the products used. In general, the developing countries use a lower grade cleaning agent than the developed countries. The Heineken Global Quality Team has a global quality guideline and needs to approve all products and suppliers. The main goal in this category is the reduction of both the chemical and water consumption to adhere to the corporate strategy of preserving precious water reserves.

5.5. Key Points

This chapter has presented the focal company, Heineken. Heineken is a global company and a large producer and exporter, producing and operating around the world. It has an unique organizational structure with its Operating Companies, which have resulted from its acquisitions of smaller brewing companies. These have a large degree of autonomy and historically have operated in different ways, which is still reflected in the day-to-day operations. The Global Departments provide the guidelines which are adhered to, but these guidelines provide enough flexibility to still be significantly different.

The HEINEKEN Company produces a lot of different beers and related products. These products are relatively similar, and uses the same types of inputs. These inputs come from different upstream supply chains, from raw materials to finished goods, but generally not very expensive or difficult to acquire. The different supply chains have a varying distance to the actual source of a raw material, and also the position of Heineken in the different upstream markets makes it anywhere from a moderate to very dominant player.

6
Research Protocol

The preceding literature review on blockchain and supply chain indicates the recent interest in the topic. Many publications write about the possibilities and promises of blockchain technology in supply chain. It is being proposed as a solution to many different problems. With regard to supply chain, traceability is one of the main issues. Traceability can be done for many reasons, in various areas.

As can be seen from the analysis of Seebacher and Schüritz [75], a lot of the variables impacting any interorganizational system also apply to blockchain technology and vice versa. Therefore it is hard for technology managers to weigh the pros and cons of blockchain versus other solutions. The work of Olsen et al. [112] is one of the sparse resources that pitches traditional product traceability systems against blockchain-enabled ones. They listed multiple criteria for choosing between the two. Both academia and practice would benefit from more resources on this comparison.

Also more material is becoming available on the challenges and barriers influencing the adoption of this new technology. The knowledge base would benefit from case studies in order to improve their usability for practice. Also it is worthwhile investigating how the different drivers for traceability change the barriers and challenges in adopting blockchain technology.

Lastly, there is little material going into the specific issues global companies might face. Very limited specific information is available on high profile blockchain proof of concepts, and the more detailed cases are usually with small size supply chains or companies.

6.1. Justification

6.1.1. Case Study

Studies may be either exploratory, descriptive or explanatory. If little is known about the phenomenon of interest, exploratory research is useful to help understand what is happening. Exploratory studies are also used when some facts are known but more research is needed. This fits the context of this research, as many different sources have touched upon the subjects but still some of the relations are unclear. The study will be in the form of a case study. Case studies are empirical inquiries that investigate a contemporary phenomenon within a real-life context where the boundaries between phenomenon and context are not evident and in which multiple sources of evidence are used [6]. This study will perform a case study to explore the role of traceability systems and the applicability of blockchain technology in the context of the HEINEKEN Company. This gives the opportunity to study how the issues are regarded in practice.

Case studies are usually qualitative in nature and typically combine data collection methods such as archival searches, interviews, questionnaires and observation [122]. While case studies may use quantitative data, a key difference with other methods is that case studies seek to study phenomena in their contexts rather than independent of context [123]. For example, experiments are designed to place phenomena outside of their context and study the results by changing a few variables of interests. The main methods for this research are the literature review and expert interviews. A small survey will also be conducted.

Critics have regarded case studies as being prone to problems with rigor in terms of validity and reliability [6][123]. Gibbert et al. note that deficient rigor can be particularly problematic for two reasons.

Quantitative	Qualitative
Cost / Revenue Analysis	Multi-Objective, Multi-Criteria (MOMC)
Return on Investment (ROI)	Value Analysis
Cost-Benefit Analysis	Critical Success Factors
Boundary Values and Spending Ratios	Experimental Methods
Information Economics	

Table 6.1: Quantitative and Qualitative Value Analysis Methods

One, as case studies are often done in the early stages of research, wrong conclusions in this phase will have ripple effects in later phases of research [124]. Second case studies are usually done in close interaction with practitioners and deal with real management situations. However, without rigor, no relevance can be claimed [123].

Four criteria are commonly used to assess the rigor of research: internal validity, construct validity, external validity and reliability [101][123][125].

- **Internal Validity** refers to the causal relationships between variables and results. However this criterion is only of interest when the study is of an explanatory nature. This research will be of the exploratory kind and will make no upfront statements about causal relationships. In exploratory studies, internal validity is not of concern [6] and will be therefore disregarded for this study.

- **Construct Validity** refers to the quality of the conceptualization or operationalization of the relevant concept, it is the extent to which a study investigates what it claims to investigate [123]. This is of big concern during the data collection phase. It should be prevented that that the researcher introduces biases to the study. Yin lists three strategies to reach construct validity: 1) use multiple sources of evidence, 2) establish a chain of evidence and 3) have key informants review draft case study report.

  This study makes uses of multiple sources of evidence, claims in this research will be backed up by collected evidence and the case company representative is involved throughout the entire process.

- **External Validity** is grounded in the intuitive belief that theories must be shown to account for phenomena not only in the setting in which they are studied, but also in other settings [123]. Case studies do not allow for statistical generalization, which is making inferences about a population based on empirical data collected from a sample of that population [6]. They can serve analytical generalization which refers to generalizing from empirical observations to theory, rather than a population [6].

  This study tries to achieve validity or external usability being providing enough background information with the cases, so readers can assess when the statements made in this research could apply to their situation as well.

- **Reliability** refers to the absence of random error, enabling subsequent researchers to arrive at the same insight if they conduct the study along the same steps [123]. In case study research this can be done by having a case study protocol and a database. The protocol specifies how the study has been executed and the database includes all notes, documents and narratives collected during the study [6]. The interview protocol can be found in Appendix A, transcripts of the interviews are saved by the researcher.

6.1.2. Project Selection Methods

Plenty has been written about methods to select projects in different business settings, including IT projects and/or supply chain management issues. For instance Farbey and Finkelstein, coming from a IT perspective, classify two types of methods: quantitative and comparative methods based on costs and benefits in economic terms, and qualitative and exploratory methods which emphasize the importance of understanding the opportunities and risks [126].

Multi-Objective, Multi-Criteria (MOMC) is a family of methods that recognizes that there are many points of view and more than one set of values in the decision to invest in a system [126]. They do not rely on monetary values, but rather establishes preferences and utilities.

Wei et al. state many companies rush the installation of supply chain management systems without understanding the business implications clearly [127]. Generally a SCM system selection is a group multiple-attribute decision making problem, in which some measures are not easily quantifiable since an individual judgment is often vague and difficult to quantify with an exact numerical value. Therefore they employed a multi-objective, multi-criteria decision method under a fuzzy environment to facilitate in the complex supply chain management process. Their method consists of three phases: strategy analysis, system analysis and group decision-making evaluation. In the strategy analysis phase the characteristic of the supply chain are recognized, which can be industry factors, client needs, product life cycle or manufacturing strategies etc. It also involves developing strategic objectives and formulating the structure of the supply chain.

The system analysis phase consists of selecting appropriate attributes and structuring their hierarchy, eliminating unqualified alternatives and holding interviews with candidate proposals and prototypes. They categorize supply chain management project selection attributes into four categories: strategy factors, project factors, system factors and vendor factors.

The strategic factors included in their case study were customer demand support, supply chain capability, domain knowledge and supply chain model design. The project factors were as follows: Total Costs (involving, basis system cost, customization, consultant, infrastructure and maintenance costs), Implementation Time, Benefits and Risks

System factors, the aspects relating more to the actual software system, were Function and Technology, including attributes like scalability, functionality, user friendliness, reliability, quality and security, System Flexibility, in this case meaning business process re-building, ease of customization, platform neutrality, System Integration, evaluating the possibility for application integration or specific SCM modules integration.

Lastly they evaluate vendor factors, based on their ability on R&D, Training and resources, Implementation and Maintenance ability, Consulting Services experience and Vendor Reputation.

In the last group decision-making evaluation phase, the attributes are weighted to their relative importance and the different proposals and rated on these attributes. This study uses linguistic terms as they are usually preferred by industry practitioners to judge intangible parameters [127]. Then they apply a fuzzy algorithm which ranks the proposals based on the ratings given.

The method is a structured way of tackling the project selection problem, looking at the entire range of attributes involved. The process is relatively easy to execute (once the algorithm has been implemented), and often the first strategic phase has already been done by company management. Their strategic goals can be used as input, rather than being a part of the process.

A critique of this method could be that it puts both benefits and risks as a single attribute, ignoring the complexity that is often involved with determining benefits and risks for complex supply chain management projects.

Value analysis is an exploratory technique, which tries to assess the incremental value of the outputs of a proposed system [126]. It involves agreeing on an estimate of the value of a proposed system and then estimating the value when certain changes are method. Finally it checks if the benefits outweigh the costs. The choice of method is dependent on the criteria that need to be weighed. In this case, intangible factors are playing an important role according to the interviewees in the focal company. Therefore these need to be taken into account and more qualitative value assessment methods are required. Value Analysis and MOMC seem to be appropriate methods.

Brun et al. discussed the introduction of a new information system for advanced planning and scheduling in a supply chain management setting [128]. They gave special attention to the value assessment of this system. Their work is based on the assumption that the activities supported by an IT system will have an effect on key performance indicators (KPI) of supply chain management. In their method they identify the information requirements. Then they collect current estimates of those KPI's and the potential improvement that could be realized by an improvement project. This estimated value is then included in a risk analysis, which takes into account a discrete probability distribution of the potential outcomes, estimated duration before benefits are gained, and some intangible strategic issues. This method is well suited when a specific context has been chosen and actual operational variables can be identified and quantified.

Caridi et al. partly builds on the value assessment model by Brun et al.. They aim to provide a method and tools to quantify the benefits that can be achieved through better visibility on the inbound supply chain [129]. The tools are ten causal maps, relating the effect improving one information flow has on certain process improvement drivers and KPI's. Their method involve customizing the cause-effect maps to the specific context, identifying the strategic KPI's that are impacted by visibility, prioritizing and selecting KPI's and estimating the performance gap, the gap between the actual value and the target. This is all done by a group of experienced managers. Next they are asked to identify the causes of this gap. Then the cause-effect maps can be used to trace back which information flows can/should be improved to close the performance gap. The potential value add of these improvements are estimated again by the managers, after which the total value of an SCM improvement project can be determined.

This process is extensive and quantifies the value of supply chain visibility. The method is human resource intensive as it relies heavily on expert judgements and is also more suited for a specific context where operational parameters can be identified and estimated. Therefore it is not suitable for high-level potential project identification. Brun et al. uses a Value Analysis method to do a value and risk assessment of supply chain management improvement projects. Caridi et al. built on this approach to study the benefits of supply chain visibility.

6.2. Data Collection Protocol

This study is being done in cooperation with The HEINEKEN Company. Heineken is the second largest beer brewer in the world and the largest Dutch beer brewer. They operate in 190 countries worldwide and produce over 240 million hectoliters on a yearly basis. Heineken was deemed a suitable candidate for a case study based on its characteristics and the opportunity to reach key individuals by cooperating with a company representative accessible to the researcher. The size of Heineken, its operating mechanisms and the fact that it a central player in its supply chain makes it a unique opportunity for the study of blockchain technology in a corporate environment. Next to that, Heineken decision makers themselves have made clear they are currently dealing with the uncertainty of blockchain technology. They are curious about the upside presented by commercial solution providers, but they still have a lot of questions about the value and implementation. Therefore, blockchain is an active topic within Heineken making it easier to motivate people to work together with this research.

6.2.1. Interviews

To assist the conversation during interviews, the interviews were semi-structured. Semi-structured interviews have some predetermined order, but still ensures flexibility in the way issues can be addressed by the interviewee [130]. Most interviews have been conducted through Microsoft Teams for Business, with a few taking place on Zoom, due to the laws and regulations put in place because of the COVID-19 pandemic. Having interviews electronically does alter the nature of the interviews a bit, but it is expected that this effect will not have been significant as the interviews were mostly internal affairs and require minimal effort to make the interviewees comfortable as they were interviewed on their expert knowledge in a familiar environment. The meetings were held in Dutch or in English and recorded with the functionalities of Microsoft Teams. Trint transcription software has been used to automatically transcribe the recordings. These transcription have been checked and thoroughly improved by the researcher. Participants were asked to consent to the use of the gathered material. The COVID-19 situation makes participant observations or other in person data collection methods impossible.

The first round of interviews has been done with several people within the Heineken organization and focused on shedding light on research question 1 and 4. The interviews have been with people who can be classified in four different categories, see Table 6.2. The first three interviews were with Global Information Systems (G01-G03), so these interviews were aimed to better understand the systems Heineken uses to communicate with suppliers. Next lead category buyers have been interviewed to understand the different product groups Heineken Global Procurement sources and there needs for traceability (P01-P05). Two interviews have been done with people involved in the downstream operations or customer service of Heineken. Both of them already had blockchain project experience within Heineken (C01-C02). The last interview was with a Quality Lead from Heineken Global Supply Chain (S01).

To answer RQ 2, 3 and further explore RQ4 the research more interviews have been conducted with experts outside the focal firm which are more engaged with blockchain currently. This group includes researcher, blockchain business developers and blockchain project leads from other similar companies.

The interviews are analyzed using the available literature. Codebooks for the traceability drivers and barriers for blockchain as interorganizational systems were available in the literature for the as

Name	Organization	Function
G01	Heineken / Accenture	Innovation Specialist
G02	Heineken	GIS Innovation Scout
G03	Heineken	Senior Technology Specialist
C01	Heineken Spain	Customer Service
C02	Heineken Netherlands	Customer Service Export
P01	Heineken	Global Category Leader - Sugar and Glucose
P02	Heineken	Global Category Leader - Adhesives
P03	Heineken	Global Category Leader - Metal
P04	Heineken	Global Category Leader - Paper
P05	Heineken	Global Category Leader - Malt
S01	Heineken	Global Quality Lead - Packaging
E01	TNO	Senior Advisor
E02	Erasmus University	Professor
E03	BlockLab	Subject Lead
E04	Henkel	R&D Manager

Table 6.2: Interviewee List

an a priori model. For the drivers of traceability this is largely based on the codebook provided by [70], whereas the categories for the barriers are based on [70], [75]. Questions on the suitability of blockchain for supply chain use cases were explicit and codes were developed from scratch.

6.2.2. Survey

The survey serves as another way to collect data to decrease the dependence on a single way of data collection. In the first part a collection of system characteristics has been developed based on literature. The respondents will be asked to indicate, based on each characteristic, whether a centralized or a blockchain-enabled performs better or should be preferred. The respondents can indicate an strong or moderate advantage for either implementation or no significant difference. The selected of characteristics and their definitions can be found below:

- *Suitability of Database for Supply Chain*: The congruence of system fundamentals and basic characteristics of supply chain networks and valuable data.
- *Data Quantity / Breadth*: The degree to which the systems holds the important information (transactions, status, master data and operational plans).
- *Data Accuracy / Precision*: The degree of conformity of the shared information with its actual value.
- *Data Freshness*: The degree of information synchronization with business partners.
- *Data Depth*: The degree to which the system can collect information on higher tier supply chain partners.
- *Integrity and Transparency*: The degree to which actors have access to the information they require to verify its integrity.
- *Confidentiality*: The ability of the system to handle information which is deemed business confidential.
- *Trust*: The ability of a player to trust the data and the actors in the network.
- *Speed and Efficiency*: The time required to read and write data to the system.
- *Robustnesss*: The sensitivity of the data and database to mistakes, errors, or incidents either accidental or malicious.
- *Interoperability with existing ERP / BI systems*: How well the traceability system can exchange information with existing internal IT infrastructure

- *Interoperability with other actors*: How well the system can exchange information with systems of other SC actors.
- *Scalability*: How well the system can handle large networks or amounts of data / transactions
- *Implementation Costs*: The costs of building and implementing the system
- *Operational Costs*: The costs of maintaining and operating the system
- *Stakeholder Willingness*: The willingness of a supply chain partner to adopt this technology implementation.

These characteristics are also weighed by the same respondents on their relevance for inclusion in deciding on traceability technology selection. . They have available a set of five linguistic expressions for each characteristic, W = VL, L, M, H, VH, where VL = Very Low, L = Low, M = Moderate, H = High, and VH = Very High.

These ratings are a Likert scale. There is a discussion if Likert scale can be treated as interval data, as they are technically ordinal scales [131][132]. Norman states that performing certain tests not intended for ordinal data can be used for Likert data. For this to be true, the distance between a rating of Very Low and Low should be equal to the distance between Moderate and High. It is impossible to prove this, but a researcher can make arguments that this is the case. Especially if the Likert scale is symmetrical, this could be the case [132]. The 5-point Likert scale used to weigh the characteristics in this survey is symmetrical and it can be defended that the difference between the items will be interpreted as similar by respondents. Therefore a mean will be calculated across the responses as an indication of their relative importance. This is done by attributing a value of 1 to Very Low, 2 to Low and so on, until a value of 5 is attributed to Very High. This result will be checked against the mode and median, which are ordinal measures to verify there are no outliers. Furthermore, the results of these weights are merely an indication and are not used in any further calculations, making it less likely to have any negative influence on the outcome of this research. The same can be done for the judging of relative advantage of the system characteristics of traditional or blockchain-based systems. Here the value of 1 is attributed to a Strong Advantage for Traditional Systems, 2 for Moderate Advantage, 3 to No Difference, 4 to Moderate Advantage Blockchain and 5 to Strong Advantage Blockchain. A score above 3 would then indicate a preference for blockchain based on that characteristic amongst the respondents and vice versa.

The results from the survey show how the two implementation options are different to each other and where they share similarities. Also the results can be used to validate the unique use case criteria, justifying potential use of blockchain, listed by the external expert interviews.

The second part of the survey takes input from both the internal interviews and the external interviews. From the internal interviews, potential use cases for a traceability system have been identified. The blockchain use case criteria from the expert interviews are also used. To quantify the applicability of those blockchain criteria to the use cases, the respondents are asked how relevant those criteria are to the use cases, indicating their relevance from *Very Low* to *Very High*. The full survey can be found in Appendix B.

7

Empirical Findings

This chapter presents the data collected during the study which can be used to answer the research questions. First, the drivers of traceability found in the interviews are disscussed, which serves as input to Research Question 1. Next up the barriers to traceability are presented which can be used to answer RQ4. After that, the results from the interviews and survey are described which connect to RQ 2 and 3, before finally showing the data connecting to the main research questions.

7.1. Drivers of Traceability

Several people in the Global Procurement were interviewed on their views about traceability, their current capabilities and their needs. All interviewees were end responsible for their Categories and all categories involved the purchase of physical products for use in the end product.

Interviewee P01 saw three main drivers for traceability: marketing, quality assurance and sustainability. He recognized that often the product provenance case is mentioned, but he challenged the business need for this traceability information. He seriously doubted the willingness of consumers to pay a premium for traceable products. Therefore he deemed the value and need for him to collect this information low.

During interview P02, the focus of traceability was much more internally focused. He wanted better visibility on the chemical consumption in the different breweries. He indicated that currently it is hard to get a grip on the actual consumption of chemicals in the brewery. This is due to the fact that, apart from the global buying agreements, breweries can also procure chemicals from local affiliates of the global chemical suppliers, which are not included in the global procurement deal. Therefore, from a global perspective, they don't always have the visibility in the total volume or on the source of the extra product.

To accomplish this, he is looking in cooperation with suppliers to install flow sensors in the production facilities to measure the actual volume of product used. The results are published usually in a supplier-owned portal and they are looking how to connect to the portals from different suppliers on a global scale. The goal is to benchmark the chemical consumption in breweries and use that data to drive down chemical consumption, leading to lower costs and better sustainability performance.

In interview P03 there was a very clear, singular goal for their current traceability efforts. Packaging is the largest contributor of CO_2 emissions in the Heineken supply chain (see Figure 5.7) and metal is one of the biggest categories in this group. Therefore to improve their sustainability performance, they want to require their first tier suppliers (can makers) to buy aluminium from smelters which use renewable energy sources. In pilot market China, they identified two smelters running solely on hydroelectric power. As Heineken is not in direct contact with the aluminium supplier, this presents the challenge to establish a product trail from this smelter to Heineken. They want this traceability system as they require a high degree of proof that the source of materials is correct, as this information will be used for consumer marketing and reporting purposes. The supplier has offered to share purchase orders or energy bills, but this was not sufficient. As the interviewee stated himself: trusting your supplier is one thing, there is hesitation to use certain information just on the merit of their suppliers word, especially for marketing campaigns. Or to quote him more directly: "In God we trust, all others pay cash".

Interview P04 concerned the paper packaging materials. This category also has some ambitious environmental objectives, which require some form of traceability. They want to source their materials from only certified suppliers or supply chains. The most common certifications in the paper industry, FSC and PEFC, focus on the sustainable management of forests worldwide, which means that if a paper packaging supplier is certified, it has to use its inputs from certified suppliers until the approved forest. This means that the full end-to-end supply chain can be certified.

Currently, 90% of suppliers have this certification. The checking, receiving and processing of supplier certifications is seen as a cumbersome job and something that could be done more efficient. This is a now a manual job, handled by one of her team members in an Excel sheet. Therefore her initial traceability efforts would be focused on automating this process and have suppliers take responsibility for uploading these documents in a common system. Having a better system would also be a requirement for her to make certain claims in reporting sustainability targets. The thought of implementing more rigorous measures like forcing suppliers to add watermarks to certified papers has been mentioned, but seen as a long term initiative that has to come from industry, as Heineken is not a dominant player in the paper market. When questioned if she saw benefits in excluding this third party for certifications, the answer was negative. The reason was that she does not have the capabilities to do this sustainability audit and the certifying party is reputable and widely known, increasing the value of the certification.

During Interview P05 the product provenance case came up again. Their interest was in providing traceability information to consumers for a specific local brand, which was made using only local ingredients. They saw blockchain as a delivery mechanism to increase trust with the consumer and were looking at its use more in a downstream capacity as locally they already had an advanced traceability system in place for the upstream side. Again, they were looking for the highest form of data integrity as providing wrong information would destroy the brand reputation more than the added information could ever provide. This statement was backed up by interview E02.

Interviews C01 and C02 had developed blockchain use cases and focused on the downstream side of operations. Both targeted the visibility of deliveries to their customers; for C01 this mainly applied to local deliveries using trucks, for C02 this included global cargo shipping. In the C01 use case, information was shared to customers on stock availability, order progress and shipping notifications. The goal here was to increase the customer satisfaction, as they wouldn't be surprised with unexpected stock-outs or shipping delays. The adjacent goal was that by having a single, shared system for customer deliveries, no conflicting records would emerge. Without a shared system, supplier and customer would have conflicting delivery times for example. These conflicts would only be spotted later, on a monthly basis, which makes resolution almost impossible. Interview E01 also indicated how many companies struggle with the lack of information in incoming shipments. Especially in stressed situations, this can cause problems with planning and operations. For the interviewees of C02, the intended goals were much more real-time and supplier focused. They wanted (near) real-time views of their shipments, so that if any of them would have an unexpected delay, they could turn to their transport partner and apply pressure to expedite the process. Next to this, for some ports it also included governmental involvement which sped up the customs process and reduced paper work. Similar use cases had also been demonstrated by interviewee E01 and E03. The company in interview E04 needed some traceability information in their blockchain pilot project relating to tax and trade regulations. To get tax exemptions in the European Union, a company needs to be able to show that its raw materials are sourced in the EU. Currently this is a labour intensive process with a lot of back and forth communication. By using a shared system, both supplier and customer improve their efficiency and it can be shared easily with the tax authority or customs agency. In this the product provenance case is used for financial reasons.

7.2. Barriers of Blockchain and Traceability

Most interviewees also had interesting insights to share about the barriers for extending their current traceability capabilities. Most mentioned was the need for external stakeholder buy-in. As supply chain traceability is inherently a process where advanced partner collaboration is necessary to receive all valuable information, creating a collaborative system is key, according to the interviewees.

It was said that some traceability efforts require a tremendous amount of players to be on board. For instance, the Heineken blockchain project *Hops On the Blockchain* was given as an example a few times. The project is generally considered to have failed within Heineken. Most prominent reason

Use Case	Interviews
Product Provenance	P03, P05, E01
Track Internal Consumption	P02
Improving Order Fulfillment	C01, C02
Decrease Administrative Workload	P04, E01, E03, E04
Sustainable Sourcing	P03, P04
Agile Sourcing	E01
Decrease Impact of Product Recalls	S01
Improve Incoming Order Visibility	E01, E02, E03, E05

Table 7.1: Traceability use cases presented by the interview.

given in the interviews was the incredible workload to record all required data. Heineken itself went to Californian hop farmers to install and manage the IT infrastructure for this project. Although the system seemed to work as intended, it was deemed that this way of working was not at all scalable, and it was abandoned. This is amplified by the belief that a tech project at this scale failing with technologically developed Californian farmers would surely fail if replicated in developing countries in Africa or the Caribbean.

Another facet of supply chain complexity was brought up in interview P01. He had strong doubts about the possibility of extended traceability capabilities. His concern was not directed at an unwillingness of their suppliers to deliver information, but at the sheer effort it would require them to be able to do this. Sugars and sweeteners are often derivatives of each other, meaning their origins can be the same, but the processes can differ or a product can be an intermediate for another product, like dextrose and fructose. He also gave the example of glucose syrup. A supplier might produce five different kinds of glucose syrup. Heineken could buy any specific mixture of these syrups, which is mixed in the truck.

Interview G02 added to this the learning they get from implementing any new technology. The chance of success for new technology is significantly higher when the ways of working are impacted the smallest way possible or at least not made more complicated. Especially in data collection efforts, manual data entry should be avoided as employees quickly lose the motivation to do this in pilots and it makes their work more cumbersome. He therefore foresees a large role for sensor and Internet of Things technology to really leverage the promises of blockchain technology.

The malt provenance case in Italy provided another view on this. They have all the information they want to provide to customers to show their local sourcing efforts. Their concern is in the delivery of that information. Ideally, they would want to print a QR code on their bottles for consumers to scan on purchase in their supermarkets. They identified two problems with this. The first was in the risk of incorrect information becoming larger as the actors involved in this chain increases. If the information behind the QR code would not only show where the malt was sourced, but also where it was brewed, and in which warehouses and supermarkets it has been, the points were data could be entered incorrectly increases. This would expose the brand reputation of Heineken to damage, caused outside their sphere of control. Also this operation would involve a more practical problem and that is the fact that labels once printed cannot be edited, so any information delivery system would have to be able to account for this and allow data entry after printing. According to interview E03, provenance cases are always hard because a physical asset has to become digital. This is hard and requires production process changes often, because if a paper-based documentation is not enough, digital data can also be manipulated. This works best if every unit has its own mark linked to a digital identity which can then be stored on the blockchain. This is separate from the choice between blockchain or centralized. There are examples of the wine industry where blockchain has been implemented with unique product identification. However here, the wine producer owns almost the entire supply chain. This might not be the best use case for blockchain, according to interview E03.

Interesting is also to look at the interviews with the two OpCo's already relatively successfully engaged with blockchain projects, Heineken Spain and Heineken Netherlands. Looking at Spain first, the interviewee was enthusiastic about the project and really wanted to drive it further within the OpCo. However, the pilot had been only with one customer and it was decided that to continue with the project, almost all suppliers would have to be onboarded to the solution. This process has been hard. Currently, they are trying to make this system a Spanish industry standard in cooperation with the startup that delivered the system.

Heineken Netherlands has cited similar reasons for not scaling up further. They also require more of their partners to be on the IBM provided solution. The underlying reason for this customer base not increasing seems to be different though. Heineken does not actively seek out partners to join this system, the entire development is being driven by IBM. They have confirmed to Heineken that many more cargo companies have agreed and signed to join the system, however to date this has yet to happen. For Heineken it is guessing why this is. Potentially this could have to do with the technological complexity of implementing a new IT system which every organization has to deal with. Heineken itself also encountered these problems when setting up and still does. Currently Heineken Netherlands does not post information to the system. The necessary information is actually uploaded downstream. The interviewees seemed to attribute this problem for the largest part to Heineken's internal IT configuration and security policies, but it does show the extra effort needed when implementing totally new IT solutions in the network.

Interview E04 shared the concern for networks not attracting enough actors. Their pilot project is with a limited set of players as of now, but the involvement of a substantial amount of other players, in their case other companies and governmental agencies, is of paramount importance for the eventual success of the platform. In their case, they attribute the lack of players currently to cold feet and the uncertainty of a new technology.

Interview SO1 illuminated another issue that could trouble the backwards traceability of products. He illustrated the case where a major product fault could happen in one of the food-touching items (raw materials or packaging with product contact). For instance with bottle caps, the batch size is half a million. If a fault is spotted downstream, relatively quickly the batch number can be collected, but this is never with one hundred percent certainty, as the production line is continuous and therefore the material is replenished before it is empty. This means there is a possibility the faulty bottle cap could be from a preceding or following batch, making the affected product size about 1.5 million. The financial and image damage related to such a product recall would be massive. This lack of granularity could also have implications for cases that want to have the highest degree of certainty when making a product provenance claim to the market. If the sustainable product is used before or after a non-sustainable product, this claim can not be made with full confidence. Seeing as Heineken's product lines are fairly advanced, the interviewee stated that this is certainly also a problem for Heineken's suppliers, making it outside of the zone of control for Heineken.

In a global supply chain, also issues as trivial as language barriers could appear, according to interview P03. Especially when collecting information that was previously not regarded as necessary, this might not be available in English. Heineken operates for the largest part in English and its suppliers cooperate in that. But in certain provenance cases, also higher tier suppliers have to deliver information to the system in the required language. It can be that this has never been in English, creating difficulties for partner cooperation.

Interview E01 also investigated complete end-to-end use cases, including the end consumer in the process for mass consumption goods. If one wants to automate the whole supply chain and allow visibility for every single end consumer, the number of transactions per minute would exceed one billion. They concluded that this is not feasible. If one wants to have some end consumer processes on the blockchain, they will have to rely on some certifications in the preceding stages. On the other hand, mature blockchain networks are totally capable to handle most logistical processes in terms of transaction speeds.

According to E01, the biggest problems facing blockchain development concerns data management. When and how long to store certain data, managing the required storage space. One option is to only store data a certain duration, another option is to not store all the data at every node. This research is still ongoing. Another is relating to confidentiality. For some, hashing the data between two parties is not enough. They want to prevent third parties seeing there is communication between two parties at all. This is mainly in logistics and export. This can be tackled by creating subdomains on the network, but it decreases the flexibility to onboard new actors as new channels have to be created between the subnetworks every time.

7.3. Blockchain Suitability for Traceability Systems

7.3.1. Interviews

Interviews were conducted with blockchain and supply chain experts and they were asked what the requirements are for a use case in supply chain to be suitable for blockchain adoption.

Interviewee E02 and E04 were very clear in that the first question is whether the problem is decentralized in nature. To be more precise, do you want to gather data from several parties with which you do not have direct contact?

They mentioned that if you only deal with first tier suppliers, blockchain is not an option, you can rely on bilateral EDIs etc. For Tier 2 and Tier 3 verification, you could give responsibility to your Tier 1 supplier. But they need to be on your quality standards and you need to have complete trust in them to achieve this. This might be an issue.

The current ways of working to trust second tier data are flawed. Often there is a paper trail, which can be forged easily. Tracing this information in a centralized manner is not achievable because of the sheer number of interactions. If you are a very dominant player you could force this, but it is not optimal for all supply chain partners.

Blockchain is suited for a dynamic supply chain with large number of players. Architecture should be that players are known as the reputation of actors is still important because of the Garbage In, Garbage Out principle. In product provenance cases you can't do without this data verification. But it is important to distinguish level of access and level of control. Visibility has low value when the level of control over the situation is low, it can sometimes work counterproductive if the data proves to be a bit inaccurate.

As a company in a supply chain, you either are the dominant player in a chain and can impose technology and standards on your partners or you are not big enough to do this and have to rely on coordination and cooperation. For dominant players, a lot of things can be arranged by using centralized systems. But still that dominance ends somewhere usually and this is starting with the second, third etc tier suppliers and distributors. For first tier use cases, you don't need blockchain. For higher tier use cases, it could be the right fit.

Immutability is a business choice. As a database structure, blockchain gives you certainty in the data that other systems will not give you. So if having the highest degree of confidence in the data is important, blockchain becomes a good option. For E04, this was a key reason to pilot with a blockchain project related to tax, where data integrity is crucial.

These problems cannot be solved by centralized trusted third party systems as the process of checking log files is almost infeasible, while for blockchain this is an inherent feature, according to interview E03.

This way also prevents companies building differing versions of the truth in their own siloed IT systems, which will prevent errors and conflicts. A great example of blockchain implementation is the Baseline protocol, which uses the Ethereum mainnet to share assets from different ERP systems. A purchase order can be published to the mainnet, were the internal data can be hashed, but then a producer can use that to create new data while linking it to that purchase order, creating a verifiable trail of records. If someone requires to see the whole information, it can request access to it at your ERP system, which can be implemented by smart contracts.

It also allows you to be in control of the data, which centralized systems do not as they require all parties to put trust in a third party which manages this database. This is a problem for many companies. The main driver for blockchain platform development like Tradelens, is that many actors want to work more with external data, but they want to control their own.

Another big reason for this choice is data sovereignty. Companies are very keen to protect their data. They are reluctant to use a system which collects, stores and distributes their data. Their blockchain solution does not store data. Data is kept decentralized, so the choice to share information remains with the data owner.

The most promising way to achieve this is by using blockchain as a connecting infrastructure layer. It is sometimes regarded as a competitor for business IT and ERP systems, but according to the interviewees the most effective implementation of blockchain in supply chain will be as the interconnecting layer between these systems. According to interview E01, this requires an open and neutral infrastructure. Companies should not burden themselves with building these networks. Telecommunication providers will build these networks if other parties will provide applications and use cases. There is public support for instance from committees at the European Commission to develop and stimulate these infrastructures. Interview E03 also recognized that there is a lot of valuable information stored in many different IT systems and what is lacking is a way to connect these. Therefore they see blockchain as the ultimate connector between disparate ERP systems. By using blockchain as a universal connector, onboarding of higher tier parties will be easier as it doesn't require expensive IT integrations to be set up. It is only needed to download the current state of the ledger. He also indicated that the best business cases are the ones were the data might already be available, but which is stored in many different IT systems. Making blockchain the interoperability layer is then a way to make this case happen without requiring large organizational change. One example is tax compliance. Using blockchain to connect this information will make your tax process more efficient, but also increases your visibility, demonstrating a high level of control over your operations. You can still use audits to check your suppliers, but an advantage of a shared blockchain can be that audits can be shared, reducing costs and time. Key question is the interoperability of blockchain platforms. A benefit with blockchain cryptography is that the veracity of data can be tested without seeing the data. Smart contracts can be implemented to automate data governance, without having to ask for human approval in seeing data.

Two different blockchain systems should only be connected if they have some interdependence. But this choice doesn't need to be made in advance. As long as you choose an open, interoperable system they can be connected later.

Some of the interviewees criticized some of the available blockchain options on the market. Most important was that the architecture of some is not a decentralized system, but rather a centralized database with some blockchain functionalities. Data is stored centrally and assets are put on a blockchain. Then cumbersome IT integrations and channels are built to connect the assets to data. They were also criticized for using proprietary data for commercial opportunities.

The recommendation for companies is that blockchain is ready for some quite mature use cases. In the past, pilots have started up, and often spun out from the original project as a blockchain platform with its own governance structure. This structure works fine for actors already on the platform, but it makes onboarding difficult. This can be prevented by investing in an open and neutral infrastructure. An opportunity possibly is to seek out support from governmental institutions. They can direct infrastructure and standard development and companies then just have to bring in use cases benefiting an entire supply chain or society.

A lot of times, supply chain managers do not identify any big problems in their supply chain. They could run much more efficiently by digitizing and automating certain parts. However, the current systems are in place to prevent faults, they work and therefore managers prefer not to change them.

An implementation project should start with a business case proposition. How much more efficient are you going to be? This is information which should be delivered by the process owner. In the case of product provenance, this is a question that should by answered by commercial departments.

As far as the cost, this is highly dependent of the project scope. It can be relatively cheap or very expensive, but this is also connected to changes in the production process that may be necessary.

The robustness and scalability of blockchain systems were also mentioned by the interviews. Interview E01 said that functionalities are quickly deployed on the network by using APIs. The functionalities operate on an open blockchain network. This infrastructure can be developed by telecommunications providers, so the network size can be extended easily when demand rises. The decentralization of data also builds a redundancy and the consensus protocols provide extra robustness.

Interview E03 was also not afraid of blockchain immaturity. The first use cases have been implemented in 2019, and while some restraint should be used with some of the newer platforms, there are plenty of small to medium-sized use cases that can be implemented right now. Blockchain is also getting support from established parties like Google and Microsoft, so implementation is getting easier.

7.3.2. Survey

A survey was conducted among supply chain and blockchain professionals. The first part of the survey served to better understand the differences between traditional, centralized systems and blockchain-enabled systems. The first part of the survey was only shown to respondents who indicated to have a Moderate or High level of experience with blockchain implementation. This part was completed by six respondents.

A collection of system characteristics was developed from literature reviews, as described in Chapter 6. First the respondents were asked to judge their importance of these individual system characteristics in the technology selection process for supply chain traceability systems. The results for this question can be found in Figure 7.1.

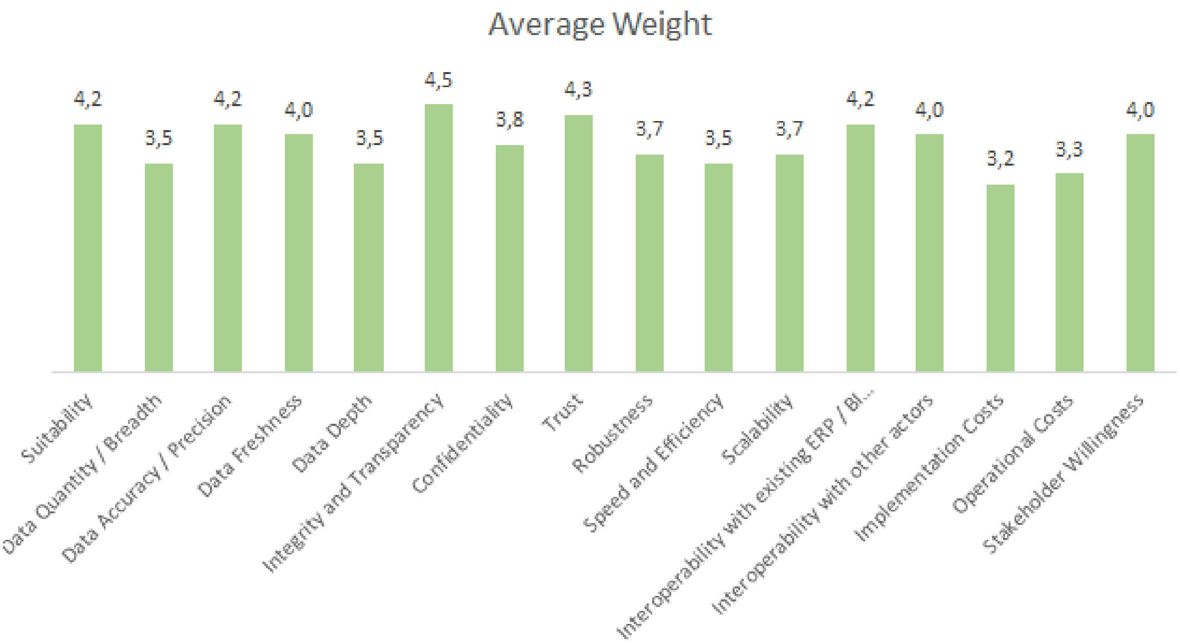

Figure 7.1: Average weights of selected system characteristics

All characteristics included in this survey were rated at least moderately important. Based on the average weight indicated by the respondents, the following ranking can be made:

1. Integrity and Transparency
2. Trust
3. Data Accuracy / Precision
4. Interoperability with existing ERP / BI
5. Suitability
6. Stakeholder Willingness
7. Data Freshness
8. Interoperability with other actors
9. Confidentiality
10. Scalability
11. Robustness
12. Data Quantity / Breadth
13. Data Depth
14. Speed and Efficiency
15. Operational Costs
16. Implementation Costs

Sixteen characteristics were included in the survey, of which eight scored High or above ($Average \geq 4.0$). *Integrity and Transparency*, the degree to which actors have access to the information they require to verify its integrity, was ruled as the most important system characteristic for a supply chain traceability project. *Trust*, the ability of a player to trust the data and the actors in the network, came in second, followed by *Data Accuracy*, *Interoperability with existing ERP's* and *Suitability*. These were all rated consistently as of High or Very High importance. Only one respondent indicated *Trust* as moderately important. Only five characteristics got a vote for Very Low or Low importance. *Robustness* was ruled Very Low by one respondent, while it was rated High or Very High by the others. The other characteristics scoring Low by one respondent were *Scalability, Data Quantity, Operational Costs* and *Implementation Costs*.

Question Five involved judging the relative advantage of either centralized or blockchain-based traceability systems on the different characteristics. Figure 7.2 displays the aggregated responses for all characteristics. In this Figure a high bar on the left of the centerline indicates a high number of responses indicating a Moderate Advantage (MA) or Strong Advantage (SA) for traditional, centralized systems and a high bar on the right indicates preferences for blockchain-based systems. The responses that indicated No Difference between the implementations have been distributed evenly to the left and right of the centerline.

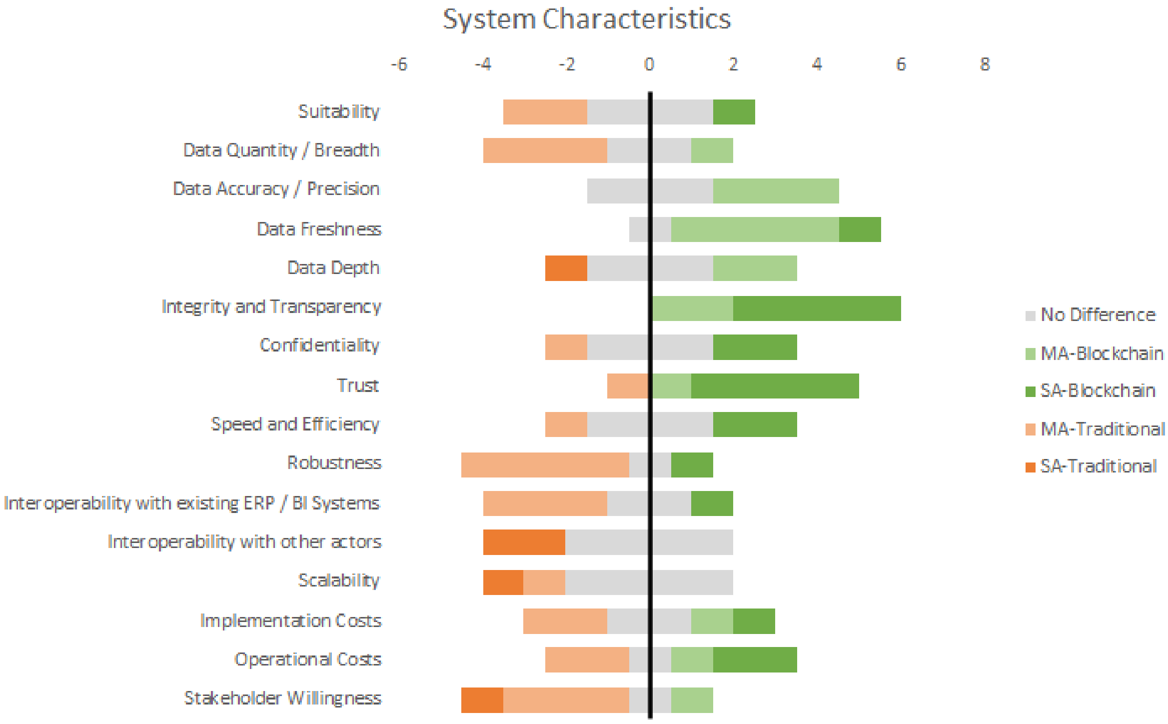

Figure 7.2: Results of Survey Question Five

When the scales are converted to numbers, an average score can be calculated. The system characteristics which have a result in favor of blockchain technology are shown in Table 7.2. Figure 7.2 and Table 7.2 show only one characteristic to be judged unanimously either way. This is *Integrity and Transparency*, which has a Moderate or Strong Advantage over traditional systems according to all respondents. The *Trust* component was also judged in favor of blockchain, with only one respondent disagreeing with the evaluation. Together with *Data Freshness*, these three components show the greatest advantages for blockchain systems.

The characteristics *Data Accuracy* and *Data Freshness* did also not show any contrary responses, although some respondents saw no significant differences on these issues.

Advantage Blockchain	Score
Integrity and Transparency	4.7
Trust	4.3
Data Freshness	4.0
Data Accuracy	3.5
Confidentiality	3.5
Speed And Efficiency	3.5
Operational Costs	3.5
Implementation Costs	3.2

Table 7.2: System Characteristic with advantage for Blockchain Systems

Two system characteristics had on average no inclination towards either technology: *Suitability* and *Data Depth* scored a 3.0 on average. It should be noted that this does not mean that it only had No Difference votes. *Suitability* saw more votes for an advantage for traditional systems, but this was offset by a strong vote for blockchain and the reverse holds for *Data Depth*.

The system characteristics that were judged to have an advantage with traditional systems are in Table 7.3. *Interoperability with other actors* and *Scalability* had no votes in favor of blockchain-based implementations.

Advantage Traditional	Score
Stakeholder Willingness	2.3
Interoperability with other actors	2.3
Scalability	2.5
Robustness	2.7
Data Quantity / Breadth	2.7
Interoperability with existing ERP / BI Systems	2.8

Table 7.3: System Characteristics with advantage for Traditional Systems

For Part 2 of the survey, the insights from the expert interviews are applied to the internal cases of Heineken. This way the use cases derived from the interviews are checked against the four criteria which could justify the use of blockchain technology. These were part of the survey and have been judged by supply chain professionals, both with and without blockchain experience. The criteria were rated on a Likert scale, ranging from Very Low to Very High. These ratings have been converted to numerical values, where Very Low = 1 and Very High = 5. The mean value of the ratings are on display in Table 7.4.

Case	**Multi Tier**	**Trust**	**Single View**	**Data Sovereignty**
Product Provenance	4.2	3.6	3.8	3.8
Decrease Impact of Product Recalls	3.8	3.2	3.8	3.4
Sustainable Sourcing	3.8	3.7	3.8	3.5
Decrease Administrative Workload	3.0	2.9	2.9	2.5
Improve Order Fulfillment	2.7	3.1	3.3	2.9
Agile Sourcing	3.1	2.9	2.8	2.9
Improve Incoming Order Visibility	2.9	2.8	3.0	2.8
Track Internal Consumption	2.8	2.6	3.0	3.0

Table 7.4: Survey Results - Averages

Looking at the first criteria, *Multi Tier Data Collection*, only four use cases score above average on the available scale, which is 3 (=Moderate). This is the case for *Product Provenance, Sustainable Sourcing, Decreasing Impact of Product Recalls* and *Agile Sourcing*. For the criteria *Trust but Verify* also only four use cases score above average. This applies to the same criteria except *Agile Sourcing*, which is replaced by *Improve Order Fulfillment*.

By calculating the average values produced by the responses, a ranking can be made of the different use cases. The rankings for *Multi-Tier Data Collection* and *Trust, but Verify* can be seen in Table 7.5.

Multi-Tier Data Collection	**Trust, but Verify**
1. Product Provenance	1. Sustainable Sourcing
2. Decrease Impact of Product Recalls	2. Product Provenance
3. Sustainable Sourcing	3. Decrease Impact of Product Recalls
4. Agile Sourcing	4. Improve Order Fulfillment
5. Decrease Administrative Workload	5. Agile Sourcing
6. Improve Incoming Order Visibility	6. Decrease Administrative Workload
7. Track Internal Consumption	7. Improve Incoming Order Visibility
8. Improve Order Fulfillment	8. Track Internal Consumption

Table 7.5: Rankings:Multi-Tier Data Collection and Trust, but Verify

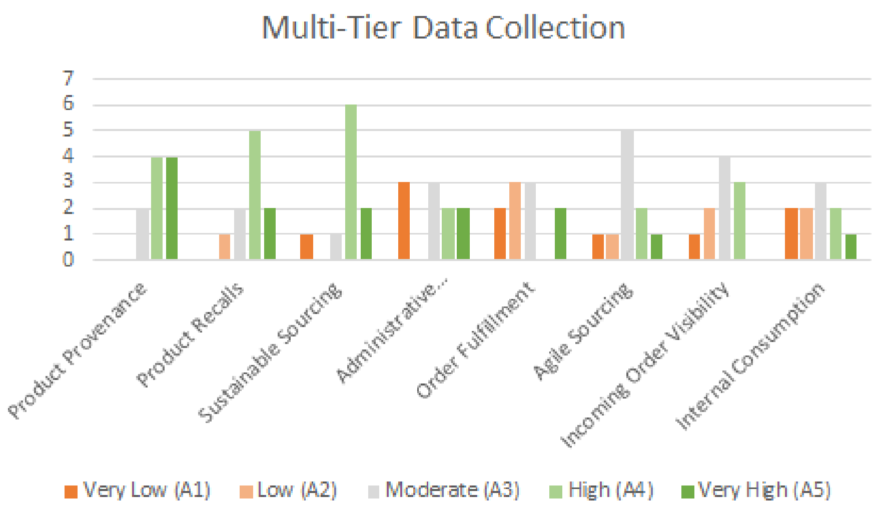

Figure 7.3: Survey Results Multi-Tier Data Collection

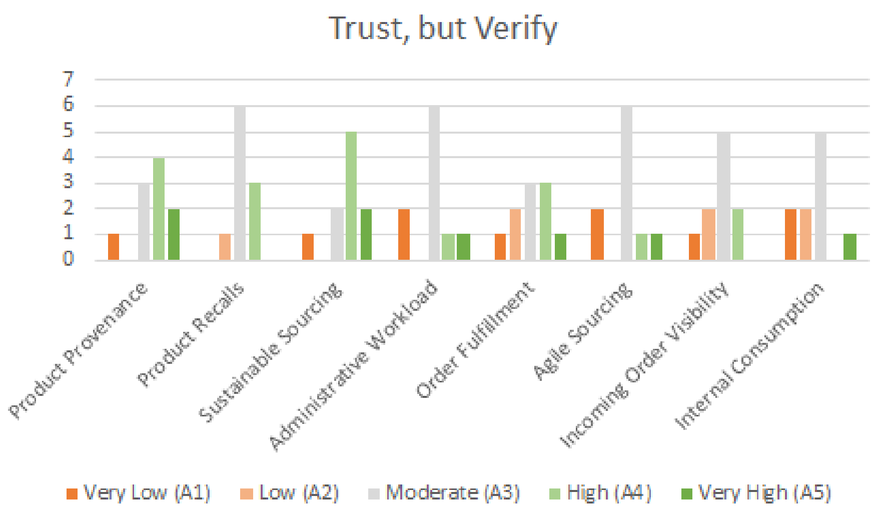

Figure 7.4: Survey Results: Trust, but Verify

This procedure can be repeated for the third and fourth criteria, similar results can be found. For a *Single, Shared View Product Provenance, Sustainable Sourcing* and *Decrease Impact of Product Recalls* score well above Moderate. Also *Improve Order Fulfillment* scores above a 3. Looking at *Data Sovereignty*, only the first three score above a Moderate Score. See Figure 7.5 and Figure 7.6. Based on the scores a ranking can be made, which is displayed in Table 7.6.

Single Shared View	**Data Sovereignty**
1. Product Provenance	1.Product Provenance
2. Sustainable Sourcing	2. Sustainable Sourcing
3. Decrease Impact of Product Recalls	3. Decrease Impact of Product Recalls
4. Improve Order Fulfillment	4. Track Internal Consumption
5. Track Internal Consumption	5. Improve Order Fulfillment
6. Improve Incoming Order Visibility	6. Agile Sourcing
7. Decrease Administrative Workload	7. Improve Incoming Order Visibility
8. Agile Sourcing	8. Decrease Administrative Workload

Table 7.6: Rankings: Single, Shared View and Data Sovereignty

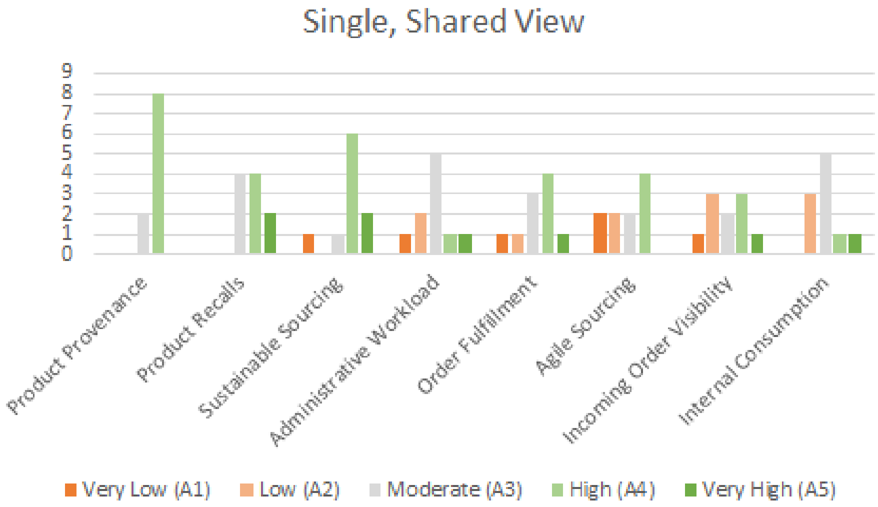

Figure 7.5: Survey Results: Single, Shared View

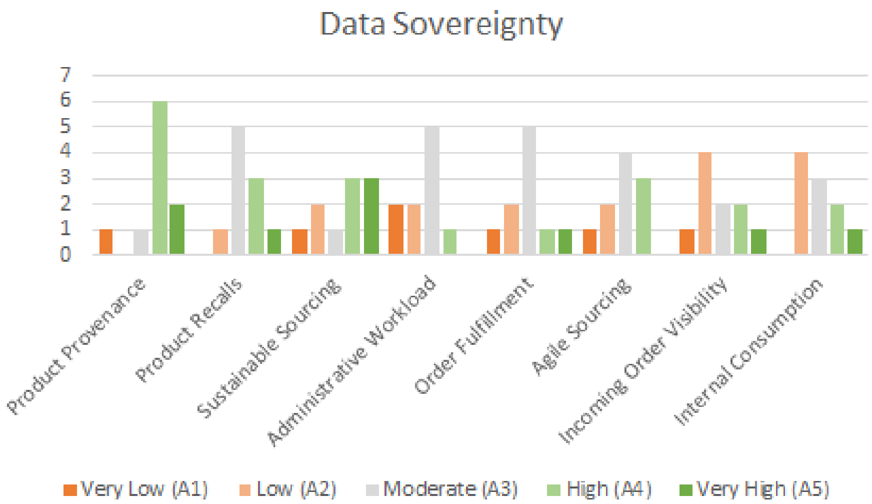

Figure 7.6: Survey Results: Data Sovereignty

8
Analysis

This chapter compares the findings from the interviews and survey executed during this study against the literature review, in the same order as the findings were presented in the previous chapter.

8.1. Traceability Drivers

It is interesting to see how literature on the subject of drivers for supply chain traceability aligns with the responses gathered from the interviews as described in Chapter 7. The framework of Hastig and Sodhi [70] identified a range of different drivers for supply chain traceability. Using the framework, the interview responses about the needs or opportunities of traceability have been analyzed.

8.1.1. Meeting Stakeholder Needs

The first driver mentioned in the framework is meeting stakeholders needs, with subgoals being transparency, compliance and demonstrating integrity. Providing transparency to various stakeholders was mentioned during different interviews. For interview P05, providing more transparent information to consumers is one of the goals of their traceability efforts. They mentioned the critical nature of customers in certain regions and their search for a traceability system in which the consumer would have total confidence. Also in other downstream applications, this driver was visible. In interview D01 providing transparency to customers was the means to achieve better customer satisfaction [97]. In Interview D02, this need for transparency also was aimed to provide better customer service, but this transparency was also bidirectional [61]. Heineken requires more transparency in the downstream supply chain to better track the status of their shipment and intervene if problems would occur before it was too late.

Compliance is certainly a factor influencing the adoption of traceability, but it hardly seems a driver for Heineken stakeholders to increase current capabilities. Multiple interviewees indicated that the Heineken supply chain is compliant as it is. But it should be noted that this compliance is based on current regulations, which could become more stringent [64][91][92], which presents some challenges for the entire industry if the One-Step Backwards, One-Step forwards architecture has to be replaced by an Event-Based Architecture according to interview S01.

8.1.2. Curbing Illicit Business Practices

The second theme mentioned in the framework is the curbing of illicit business practices. It was noticeable that almost all interviewees expressed a high degree of trust in the business intentions and compliant processes of their supply chain partner or their confidence in the Heineken Quality Assurance operations to verify product quality and supplier validation. Therefore, illicit business practices were never mentioned as a primary driver for extended traceability capabilities. It should however be noted that trusting your supplier is one thing, there is hesitation to use certain information just on the merit of their suppliers word, especially for marketing campaigns. To quote an interviewee: ”In God we trust, all others pay cash”. To prevent the incident of a single supplier falsifying information some interviewees were interested in fool-proof validation of supplier information. This information would be used for marketing purposes later on. Corruption was also a problem mentioned in different interviews, with experience in dealing with governmental affairs, primarily customs, for example during the export of products across the world. In certain countries where there is a high degree of bureaucracy at customs, government officials can impose arbitrary rules and fees, thereby holding the goods in port. Due to this, companies are facing high costs. Akyuz and Gursoy mentioned preventing counterfeit products from reaching the market as one of the reasons to implement blockchain [58]. An explanation for the difference between the results found in this study could be that this often refers to high margin products [62] like expensive wines [105] or the diamond industry [85]. The profit margins on beer and its inputs is much lower, giving much less incentive for counterfeit products.

From the external interviews, it arose that illegal practices might be more common when the supply and demand balance is under huge stress, for instance in crisis situations. Then the transparency created by blockchain solutions could be a reason for developing. As an example they gave the medical supply chain during the COVID-19 crisis, where a lot of fraud and tampering with certificates occurred. Similar situations could occur to ”regular” raw materials. In water scarce regions one might like to know the source. All other categories can also be severely impacted by natural disasters or economic effects, making the incentive for illegal practices higher.

8.1.3. Improving Sustainability Performance

Third driver for traceability is improving sustainability performance. Several aspects of this came up regularly when talking about traceability initiatives, but exclusively with regard to environmental sustainability. In interviews P02, P03 and P04, category leads were concerned about their impact on nature, where in Chemicals this was directed towards Heineken’s own consumption and internal traceability and in P03 and P04, this was focused on supplier selection based on certain sustainability parameters. Social issues were only mentioned once as a reason for more traceability and spoken more in a general sense. This is in contrast with sources like [70] or [67][68]. As Heineken is a global company with supply chains reaching to virtually all countries of the world and impacting people from all societal standings, it is noteworthy that environmental sustainability is high on the agenda, while social sustainability is not, although both are included in their Brewing a Better World Program (see Figure 5.4 [117].

8.1.4. Increasing Operation Efficiency

The fourth factor is improving operational efficiency, which is a broad category. Interesting is that people in Procurement did not note error elimination as a reason to increase traceability efforts, but interviewee S01 mentioned that current traceability systems function, but lack the granularity to respond very quickly to major product faults in beverage-touching raw materials. Most of these problems are taken away by a decent quality assurance system, but the rare cases still could have a very significant impact on the finances and reputation of Heineken. Interview E02 indicated that building extra protection against product faults can be very worthwhile, especially for A-level brand production lines like Heineken. The interviewees with downstream related function, did mention error elimination as a reason. Interview C01 required it for the current mismatch in data between Heineken and its customers on delivery times etc.

Next to reducing errors this way, it also significantly speeds up their process by requiring less communication between Heineken and its customers to clear up the mistakes. This decrease in administrative workload is also sought in other areas, like interviewee P04 or by having better information on incoming delivery times, like in interview E01, E03. Also in the tax related use case of E04, process streamlining and making less errors was definitely of interest.

It is hard to say how to judge this common feeling that error elimination is not a critical goal of traceability. On the one hand, the supply chain of Heineken is one the most intricate in the world, on the other hand safeguarding quality is one of the core reasons in literature for traceability [63][101][104].

8.1.5. Enhancing Supply Chain Management

The fifth element enhancing supply chain management was mentioned in all interviews, but not as broad as described in [70]. For instance the gaining of a competitive advantage was important to all interviewees, albeit for sometimes different reasons. People were looking to gain business advantages and adapting to changing markets or they were looking to provide customer satisfaction by providing more information to their downstream suppliers. It was never mentioned that buyers expected their supplier relationships to improve by receiving or giving more information upstream. A reason for this could be the fact that Heineken is never the smallest player in a particular value chain, often the biggest or at least significant. Most value chains in the interviews consisted of a few global players, especially upstream. In most chains, Heineken was their biggest customer, for instance in aluminium. In other areas, like paper or sugars, other players might be larger, but the loss of Heineken business would still be a financial impact no supplier would be willing to bear.

In downstream use cases, Heineken's stakeholders were mostly interested in solving information asymmetries to benefit their customers. In upstream applications, risk mitigation and operational efficiencies were most interesting.

The governance of supply chain partnerships through traceability also includes the potential for disintermediation [7][13][58]. Outside of the Interview P04, the subject of disintermediation did not come up. This could be explained by the fact that most third party interaction is legal or government based and independent NGO's giving out certifications are seen as valuable rather than a distraction. This is backed up by the statements from [112] that in the food industry reputation is very important and this can be increased through these NGO's. Furthermore the fact that blockchain increases interoperability, it makes cooperation with third parties easier rather than obsolete.

8.1.6. Sensing Market Trends and Forces

Lastly, the literature review of Hastig and Sodhi showed that sensing market trends and forces could be an important driver for traceability systems. Some of the factors have already been mentioned in combination with previous drivers, like increasing consumer demands and corporate social responsibility scrutiny. The authors differentiate between globalization, supply chain risk and uncertainty, business innovation and other trends, in which they include mostly sustainability factors and consumer demands. The interviewees did not mention increased globalization as an influencing factor. The Heineken supply chains have been global for decades, so dealing with international trade is not a new factor. Also interestingly, the trends mentioned in supply chain risk theme seemed to be more a stopper than a driver for extended (blockchain-based) traceability. Especially the growing IT complexity and organizational complexity of the Heineken organization were mentioned as concerns to start with new technologies. Unsurprisingly, the need for business innovation was mentioned primarily by interviewees from Heineken Global Information Systems. There is a need to experiment with new promising technologies, learn, and capture first mover advantages.

This reluctance, especially relating to blockchain, is understandable. As shown by [83][84], putting trust in a technological artefact is a difficult concept and [75] note the uncertain benefits and [2] note the opportunity for first movers to influence standards development.

8.2. Barriers of Blockchain and Traceability

The literature review provided challenges either to blockchain systems as interorganizational systems, and for traceability in (food) supply chains in specific.

8.2.1. General

In literature review on barriers to implementation of blockchain systems as interorganizational systems, a lot of attention was given to [75] which grouped barriers in three categories: technical, organizational and network barriers. Together with [70] it served as the foundation of the review of challenges as they shared a lot of similarities and therefore seemed to be a good framework to evaluate the statements made by the interviewees.

Regarding the technical challenges, although most were present in the interviews, they did not seem to be regarded as the most pressing issues. Lack of technical capabilities was mentioned as a concern in applications or parts of the world, but for most cases, blockchain as a technology was not seen as wildly more complicated than any other technology. As indicated by a few interviewees, implementing a system based on EDI can also become very expensive and depending on the application, some blockchain platforms are easily accessible through API's etc. [75], [101] also pointed out the lack of blockchain standards as a challenge. While this is certainly the case, as pointed out by [112] and interview S01, missing standards is one of the biggest problems for interorganizational systems in general and with a few blockchain platforms taking a forerunner position in corporate use cases, this variety in platforms is not any more extreme than present in centralized systems.

From the organizational barriers, not many seemed to play an important role in the interviews. Some things like internal resistance, top management support and legal barriers were mentioned, but seen as part of any project. A lot of people did raise concern for technology driven implementations, but with the people that had concrete plans for blockchain, there were business goals they wanted to be met. Furthermore, the issue of missing awareness and perceptions of benefits was clearly present in blockchain use cases. Business cases were on top of mind, but supply chain professionals found it very hard to judge blockchain on its true worth [75]. This being the case, in Chapter 3 plenty of resources were presented that underline the benefits that can be provided with advanced collaboration [50][51][79].

Seebacher and Schüritz [75] stated that fostering a collaborative mindset is hard for blockchain as it lacks a central authority to foster collaboration [87][88]. Manrique also noted that companies could feel uncomfortable in these new roles [84]. Although for some use cases, this could certainly be true, a fair number of interviewees indicated that a blockchain project does not exclude any central authority from being involved. For example in the tax case of interview E04, he saw a large role for governmental organizations and/or technology providers to drive this development.

Some interesting notions were made in [75] about data control. It found, together with [88], that security and the decentralized nature of blockchain were reasons for doubt. From the interviews and survey, the contrary seemed to be true. Blockchain implementations scored much higher on integrity and transparency and multiple blockchain experts indicated that a blockchain, if implemented correctly, gives much more control over the visibility of data then in a centralized system.

Seen as another challenge for blockchain implementation was the bandwagon effect [75], where companies would adopt this technology because of the hype. While this may have been the case in the early years of blockchain, some interviewees indicated that the amount of actors joining a blockchain network is not large enough yet. The hype has caused a reluctance to adopt currently, delaying operational implementation and one of the main reasons this study was conducted. Furthermore, the existence of many blockchain decision frameworks [8][34][43] indicates that this hype has taken some precautions.

The challenge held up strongest with regard to network effects were the formalization of processes and relationships and the fulfillment of new roles. Expanding traceability capabilities on a large scale will require new ways of working, and these projects using blockchain, will have to be led by someone else than a single focal company, part of a supply chain. This gap was illustrated both by literature [75][90][101] and interviews, for example E04. Network management and data governance are one of the primary research areas.

8.2.2. Traceability

With regard to traceability challenges, a lot of points made by [70] [99] [101] were presented during the interviews. One of the most mentioned challenges in traceability was the mixing of products and the difficulty of linking a physical asset to a digital entity throughout the supply chain [95]. As interviewee S01 indicated, for some applications, the information granularity should be increased and as a couple of interviewees indicated product provenance use cases will require some potentially large process changes. This could be for instance watermarking of the products by suppliers, which increases difficulty, but it is not new as it was mentioned that glass bottles already contain watermarks. It would require integrating more sensors and readers read the labels throughout production lines, instead of just on product receipt and for Heineken the standardization of product labels. The mention of Heineken is specific, as indicated by interviewee G03 and S01, Heineken has no problem matching external product codes to internal product codes (if read and processed at all), but across Heineken facilities these could be different. This is attributed to the unique structure of Heineken where local Operating Companies have a lot of autonomy. This standardization challenge therefore does not need to be present in all companies depending on their current traceability capabilities and internal standards conformity.

8.3. Blockchain Suitability for Traceability Systems

8.3.1. Blockchain and Centralized Systems

Olsen et al.[112] provided a reference source of the comparison of certain characteristics between centralized and blockchain systems. Their evaluation was based on suitability of database, data quality and veracity, immutability, integrity and transparency, confidentiality, trust, robustness, speed and efficiency, and interoperability. This study included all of these characteristics to check the validity of these findings. In this case, the data quality and veracity characteristic was split up in a few subcriteria for a more precise comparison, based on other literature [115]. With regard to the suitability of database structure, no significant advantage was found either way. Olsen et al. stated that operations in (food) supply chains are similar to transactions. This sentiment was however not shared by the respondents who judged either implementation equally appropriate. Looking at the data characteristics included in the study, representing the Data Quality and Veracity (Data Accuracy, Data Freshness) these were clearly in favor of blockchain. This conclusion is similar to [112], but the comparison in this study favors blockchain stronger. The strongest advantage in the survey was given to Integrity and Transparency. The direction of the judgment is similar, although it is much stronger than in [112], the same applies to the Trust criteria.

On confidentiality, blockchain scored slightly higher than centralized systems, which is opposed to the results from [112]. Their claim was that centralized system have an easier tiered level of access. This statement is directly in contrast with some statements by interviewees that data access is much easier controlled on blockchain using smart contracts. Robustness was also judged differently between the survey and [112]. This could be explained by a difference of interpretation. On the one hand robustness could be equated by duplication and backups, but it could also be interpreted as maturity. Speed and efficiency too was judged different.

Interoperability was split up between ERP interoperability and external interoperability and the subject was also very dominant in the interviews with blockchain experts.From the interviews and [112] interoperability was one of the key selling points of blockchain currently, but based on the survey it looks in favor of traditional implementations. In the interviews, when interoperability was mentioned, it usually referred to this external interoperability with other actors.

8.3.2. Blockchain Use Case Criteria

From the interviews, the most important reasons to choose for a blockchain-based traceability system are the following.

- The network is decentralized, meaning it involves multi-tier suppliers and/or distributors.
- High degree of proof of integrity is required.
- There is a desire to obtain a single view / version of the state of the system.
- Data Sovereignty is essential.

It should be mentioned that the decentralized nature of a network was seen really as a requirement for using blockchain, while the other were more business decisions. Applying the criteria to the use cases present within Heineken, the results can be seen in Figure 8.1. Product Provenance, Sustainable Sourcing and Decreasing the Effect of Product Recalls scored high on the blockchain criteria. These use cases share similarities as they are all related to tracing the history of products, most notably on location. Therefore it makes sense that they are together on top of the list.

The use cases that score lower on these criteria are cases where the amount of actors in the relevant process is lower. Questions can be raised to what degree intermediaries between the supply chain tiers, like logistics providers, make a network decentralized. It does involve multiple actors, but often the direct relation between buyer and seller remains.

An interesting notion that can be made from the interviews, which was not present in the survey, was the lack of desire for disintermediation, removing third parties from certain processes. If anything for supply chain use cases, blockchain makes cooperation with third parties more convenient, like in the business case of E03/E04 and CO2. In this case, a governmental agency is often the third party, for instances with tax or customs. This creates the potential for industry wide cooperation or new supply chain partnerships. Tax audits and international trade regulations are an issue for every company doing international business. Defining a use case focused on government requirements, could spark cooperation between the car industry and the food supply chain or even between competitors. As was indicated by interviews E01, E04 and G02, there are use cases where rivaling companies could be willing to cooperate when both parties receive benefits, for instance with streamlining trade and regulatory affairs.

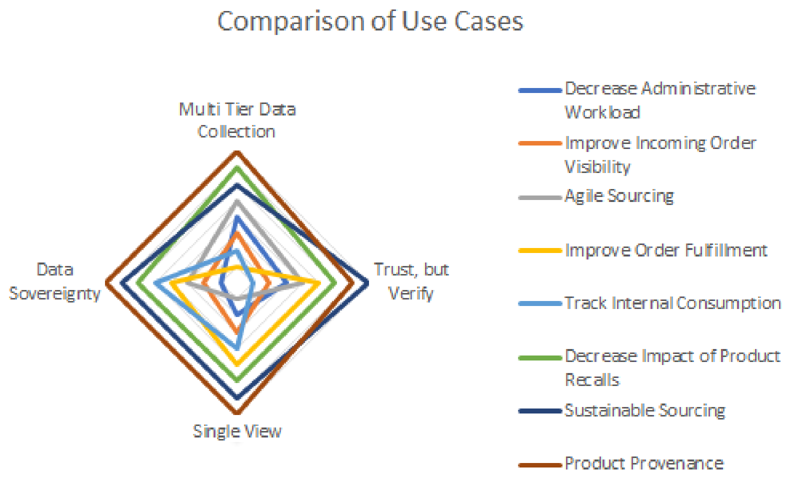

Figure 8.1: Radar Chart Blockchain Criteria on Traceability Use Cases

9

Concluding Remarks

9.1. Conclusion

This thesis tackled the problem of uncertainty in selecting use cases for the application of blockchain-enabled traceability systems. The research was executed with a case study in cooperation with The HEINEKEN Company, a global company in the food supply chain and brewing industry. Therefore attention was given to the specific needs and challenges of this industry. For the first part of this thesis an extensive literature review was conducted, before interviewing experienced supply chain or procurement professionals and blockchain experts, as well as conducting a survey.

RQ1: What drives the demand for traceability in food supply chains?

First the needs for traceability were studied in order to answer the first research question. Based on the literature review, many studies suggest that food safety and quality are the primary drivers for an increased attention to traceability. However, these suggestions from literature were not confirmed in this case study. The Heineken supply chain and quality systems are sophisticated and quality faults that may end up in the market are rare. This is partly explained by the fact that the beer industry is characterized by processed products, whereas the concerns with quality degradation are higher for fresh produce. The needs for traceability in Heineken are mainly related to consumer demands and operational efficiency. Sustainable or local sourcing and decreasing costs related to mismatched information between Heineken and its suppliers or customers are dominant elements in the case study. In these situations, trust in data integrity is critical, which leads to certain managers looking to increase their traceability capabilities.

RQ2: How do traceability systems based on blockchain compare to centralized systems?

Next, blockchain traceability systems were compared with traditional, centralized systems in order to answer the second research question. Blockchain is an immutable and decentralized ledger. The information can be trusted to be unaltered in the sharing process along the supply chain. The ledger is stored decentralized, giving all participants in the network the same view of the current state of the ledger. Although the two implementations are distinct from a technological point of view, it was found that in its usage they are not that different. It was not mentioned that blockchain systems could fulfill use cases that traditional systems could not handle with regard to supply chain traceability. The most important advantages for blockchain were related to the aspects: *Integrity and Transparency, Trust* and *Data Quality*. These criteria were also found to be the most important among an array of criteria for traceability use cases.

RQ3: Which criteria make a use case in the food supply chain suitable for blockchain technology?

When selecting use cases, four criteria were found to be of importance according to subject experts and could justify the use of blockchain technology in a supply chain setting:

- The network is decentralized, meaning it involves multi-tier suppliers and/or distributors.
- A high degree of proof of integrity is required.
- There is a desire to obtain a single view / version of the state of the system.
- Data Sovereignty is essential.

First, blockchains were meant to connect actors which are decentralized. In a supply chain setting, this means that use cases should involve actors with whom the focal company does not have direct relationships. Furthermore, for use cases where the highest degree of data integrity, a single version of the truth and data sovereignty were required, blockchain was referred to as a strong candidate. These findings are in line with the results from the survey.

> *Main RQ: Which food supply chain traceability use cases are suitable for the application of blockchain-enabled systems?*

Using this knowledge on the use cases identified during the internal interviews, it was found that for product provenance applications, including sustainable sourcing or product recall objectives, the needs for the strong sides of blockchain were the highest. This is in line with statements made in literature or by commercial blockchain providers. These applications demand end-to-end traceability and its information is tied to either the biggest value or impact, which therefore explain why these three are the most interesting use cases for blockchain use.

> *RQ4: Which challenges exist for successful traceability system implementation in food supply chains?*

Traceability with blockchain is however not without its challenges. Blockchain has been presented as a disruptive solution, but in reality many of the challenges associated with certain use cases persist. Data availability is of key concern and the challenges of gathering data are rather context dependent, relating to the specific situation. Large costs could be associated with transforming production lines or changing processes. It is not so much tied to the choice of database structure.

9.2. Discussion

This implies for industry decision makers that the choice to implement blockchain is not a choice between blockchain or centralized systems, but rather an issue of the traceability business case in general. The business case has to be made for each case individually, whereafter the availability of data can be assessed, which results in a list of changes and associated costs which are necessary to deliver the information. Only then is it an issue of blockchain versus centralized systems.

A recommendation from this research is to identify the traceability applications where information is already present in different IT systems across actors, but where the linking of these data assets is preventing successful traceability use cases. If this is the case and if the network is decentralized, this could make a good blockchain proof of concept. This prevents a situation from arising where significant data capture investments will be needed.

Although the research has been conducted with a specific company in the food industry at its centre (i.e. Heineken), many of the findings should hold true for other industries as well. The demand for local and sustainable products is not exclusive to the food industry and improving operational efficiency through better information sharing has been one of the key research areas for supply chains in general for decades. The identified use cases resulting from the case study are all general. Although it must be said that, as with any case study, things that are unique to other industries will not be taken into account. Therefore the list of drivers and challenges should not be seen as exhaustive. It should also be noted that Heineken is a unique company from an organizational perspective, which makes some of its internal issues not applicable to other companies. A possible limitation is be the sample size of the responses of the survey. Finding qualified respondents for a specific subject is hard and therefore the survey was not answered on a large scale. Confidence in the results could be improved by administering the survey with a larger population.

This research focused on understanding the differences between blockchain-based and centralized traceability systems. As said before, the most important learning is that a blockchain decision making process should be focused on the value which the information will provide rather than the choice of technology. Further research could therefore focus on building these business cases and quantifying the benefits related to traceability information. Blockchain will undergo development for many more years, and from a technical perspective data management and storage will be key elements. From a data governance and supply chain governance perspective, research needs to be done on how these systems should eventually be managed on a industrial scale. From an innovation adoption perspective, interesting questions to be explored are how these partnerships should be formed and developed, who should drive innovation, and how to tackle the transition phase of industry pilots to government/industry-driven adoption.

Bibliography

[1] Henk Zijm, Matthias Klumpp, Alberto Regattieri, and Sunderesh Heragu. Operations, Logistics and Supply Management: Definitions and Objectives. In Henk Zijm, Matthias Klumpp, Alberto Regattieri, and Sunderesh Heragu, editors, *Operations, Logistics and Supply Management*, pages 27–42. Springer, 2019. doi: 10.1007/978-3-319-92447-2.

[2] Christian Burmeister, Dirk Luttgens, and Frank Piller. Business Model Innovation for Industrie 4.0: Why the "Industrial Internet" Mandates a New Perspective on Innovation. *Die Unternehmung*, 70(2):124–152, 2016. doi: 10.5771/0042-059x-2016-2-124.

[3] Luya Wang and Shaoyong Guo. Blockchain Based Data Trust Sharing Mechanism in the Supply Chain. In *International Conference on Security with Intelligent Computing and Big-data Services*, volume 733, pages 43–53. Springer International Publishing, 2018. doi: 10.1007/978-3-319-76451-1.

[4] Guido Perboli, Stefano Musso, and Mariangela Rosano. Blockchain in Logistics and Supply Chain: A Lean Approach for Designing Real-World Use Cases. *IEEE Access*, 6:62018–62028, 2018. doi: 10.1109/ACCESS.2018.2875782.

[5] Satoshi Nakamoto. Bitcoin: A Peer-to-Peer Electronic Cash System, 2008. URL www.bitcoin.org.

[6] Robert K Yin. *Case Study Research: Design and Methods*. SAGE Publications, Thousand Oaks, CA, 5th edition, 2014. ISBN 978-1-4522-4256-9.

[7] Tomaso Aste, Paolo Tasca, and T Di Matteo. Blockchain Technologies : foreseeable impact on industry and society. *Computer*, 50(9):18–28, 2017. doi: 10.1109/MC.2017.3571064.

[8] Karl Wust and Arthur Gervais. Do you need a blockchain? In *Proceedings - 2018 Crypto Valley Conference on Blockchain Technology, CVCBT 2018*, pages 45–54. Institute of Electrical and Electronics Engineers Inc., 11 2018. doi: 10.1109/CVCBT.2018.00011.

[9] Paolo Tasca and Claudio J. Tessone. A Taxonomy of Blockchain Technologies: Principles of Identification and Classification. *Ledger*, 4, 2 2019. doi: 10.5195/ledger.2019.140.

[10] Amina Badzar. Blockchain for Securing Sustainable Transport Contracts and Supply Chain Transparency. Master's thesis, Lund University, Helsingborg, 2016.

[11] Melanie Swan. *Blockchain: Blueprint for a new economy*, volume 293. O'Reilly, 2015. ISBN 9781491920497.

[12] Nigel Smart. *Cryptography: An Introduction (3rd Edition)*. McGraw-Hill College, 2004. ISBN 978-0077099879.

[13] Juri Mattila. The Blockchain Phenomenon: The Disruptive Potential of Distributed Consensus Architectures. *ETLA Working Papers*, 38, 2016. URL http://pub.etla.fi/ETLA-Working-Papers-38.pdf.

[14] Leslie Lamport, Robert Shostak, and Marshall Pease. The Byzantine Generals Problem. *ACM Transactions on Programming Languages and Systems (TOPLAS)*, 4(3):382–401, 7 1982. doi: 10.1145/357172.357176.

[15] Karl J. O'Dwyer and David Malone. Bitcoin mining and its energy footprint. In *IET Conference Publications*, volume 2014, pages 280–285, 2014. doi: 10.1049/cp.2014.0699.

[16] Yoad Lewenberg, Yoram Bachrach, Yonatan Sompolinsky, Aviv Zohar, and Jeffrey S Rosenschein. Bitcoin mining pools: A cooperative game theoretic analysis. In *Proceedings of the International Joint Conference on Autonomous Agents and Multiagent Systems, AAMAS*, volume 2, pages 919–927, 2015.

[17] Binance Academy. Delegated Proof of Stake Explained | Binance Academy, . URL `https://www.binance.vision/blockchain/delegated-proof-of-stake-explained`.

[18] Binance Academy. Proof of Authority Explained | Binance Academy, . URL `https://www.binance.vision/blockchain/proof-of-authority-explained`.

[19] CoinCentral. What is Proof of Capacity? An Eco-Friendly Mining Solution - CoinCentral. URL `https://coincentral.com/what-is-proof-of-capacity/`.

[20] Hyperledger Sawtooth. PoET 1.0 Specification — Sawtooth v1.2.4 documentation. URL `https://sawtooth.hyperledger.org/docs/core/releases/latest/architecture/poet.html`.

[21] Brian Curran. What is Proof of Elapsed Time Consensus? (PoET) Complete Beginner's Guide, 2018. URL `https://blockonomi.com/proof-of-elapsed-time-consensus/`.

[22] Miguel Castro and Barbara Liskov. Practical Byzantine Fault Tolerance. *Proceedings of the Third Symposium on Operating Systems Design OSDI '99*, (February):1–172, 1999. URL `http://pmg.csail.mit.edu/papers/osdi99.pdf`.

[23] Blockchain at BerkeleyX. [CS198.2x Week 1] Practical Byzantine Fault Tolerance - YouTube, 2018. URL `https://www.youtube.com/watch?v=IafgKJN3nwU&t=91s`.

[24] Arati Baliga. Understanding Blockchain Consensus Models. Technical Report April, 2017. URL `www.persistent.comhttps://www.persistent.com/wp-content/uploads/2017/04/WP-Understanding-Blockchain-Consensus-Models.pdf`.

[25] Stellar Development Foundation. On Worldwide Consensus – A Stellar Journey – Medium, 2015. URL `https://medium.com/stellar-development-foundation/on-worldwide-consensus-359e9eb3e949https://medium.com/a-stellar-journey/on-worldwide-consensus-359e9eb3e949`.

[26] Matthijs Renders. A Simple Guide to Understanding the Stellar Blockchain Network. `https://hackernoon.com/a-simple-guide-to-understanding-the-stellar-blockchain-network-3609d728e9a7`, 2018.

[27] Johannes Innerbichler and Violeta Damjanovic-Behrendt. Federated byzantine agreement to ensure trustworthiness of digital manufacturing platforms. In *CRYBLOCK 2018 - Proceedings of the 1st Workshop on Cryptocurrencies and Blockchains for Distributed Systems, Part of MobiSys 2018*, pages 111–116, New York, New York, USA, 6 2018. Association for Computing Machinery, Inc. doi: 10.1145/3211933.3211953.

[28] Zibin Zheng, Shaoan Xie, Hongning Dai, Xiangping Chen, and Huaimin Wang. An Overview of Blockchain Technology: Architecture, Consensus, and Future Trends. In *Proceedings - 2017 IEEE 6th International Congress on Big Data, BigData Congress 2017*, pages 557–564. Institute of Electrical and Electronics Engineers Inc., 9 2017. doi: 10.1109/BigDataCongress.2017.85.

[29] Sjors Hijgenaar. Electric vehicles: the driving power for energy transition. Master's thesis, Delft University of Technology, 2017.

[30] Bitfury Group and Jeff Garzik. Public versus Private Blockchains Part 1: Permissioned Blockchains, 2015. URL `https://bitfury.com/content/downloads/public-vs-private-pt1-1.pdf`.

[31] Garrick Hileman and Michel Rauchs. 2017 Global Blockchain Benchmarking Study. *SSRN Electronic Journal*, 2018. doi: 10.2139/ssrn.3040224.

[32] Kyle Torpey. Eric Lombrozo: Bitcoin Needs Protocol Layers Similar to the Internet - Coinjournal. URL https://coinjournal.net/eric-lombrozo-bitcoin-needs-protocol-layers-similar-to-the-internet/.

[33] Colin Platt. Of permissions and blockchains: A view for financial markets, 2017. URL https://medium.com/@colin_/of-permissions-and-blockchains-a-view-for-financial-markets-bf6f2be0a62.

[34] Marianna Belotti, Nikola Božić, Guy Pujolle, and Stefano Secci. A Vademecum on Blockchain Technologies: When, Which, and How. *IEEE Communications Surveys and Tutorials*, 21(4): 3796–3838, 10 2019. doi: 10.1109/COMST.2019.2928178.

[35] Kyle Croman, Christian Decker, Ittay Eyal, Adem Efe Gencer, Ari Juels, Ahmed Kosba, Andrew Miller, Prateek Saxena, Elaine Shi, Emin Gün Sirer, Dawn Song, and Roger Wattenhofer. On Scaling Decentralized Blockchains Initiative for CryptoCurrencies and Contracts (IC3). *International Conference on Financial Cryptography and Data Security*, pages 106–125, 2016. URL http://fc16.ifca.ai/bitcoin/papers/CDE+16.pdf.

[36] Tien Tuan Anh Dinh, Rui Liu, Meihui Zhang, Gang Chen, Beng Chin Ooi, and Ji Wang. Untangling Blockchain: A Data Processing View of Blockchain Systems. 2017. doi: 10.1109/TKDE.2017.2781227. URL http://www.ieee.org/publications_standards/publications/rights/index.html.

[37] Camilla Valeria Cavaliere. A case study on the exploration of Blockchain potential. Master's thesis, Delft University of Technology, 2018.

[38] Alan Karp, Harry Haury, and Michael Davis. From ABAC to ZBAC: The evolution of access control models. In *5th European Conference on Information Management and Evaluation, ECIME 2011*, pages 202–211, 2011. ISBN 9781629934310.

[39] Elli Androulaki, Artem Barger, Vita Bortnikov, Srinivasan Muralidharan, Christian Cachin, Konstantinos Christidis, Angelo De Caro, David Enyeart, Chet Murthy, Christopher Ferris, Gennady Laventman, Yacov Manevich, Binh Nguyen, Manish Sethi, Gari Singh, Keith Smith, Alessandro Sorniotti, Chrysoula Stathakopoulou, Marko Vukolić, Sharon Weed Cocco, and Jason Yellick. Hyperledger Fabric: A Distributed Operating System for Permissioned Blockchains. *Proceedings of the 13th EuroSys Conference, EuroSys 2018*, 2018-Janua, 2018. doi: 10.1145/3190508.3190538.

[40] Lennard Segers. The Design of an Open, Secure and Scalable Blockchain-Based Architecture to Exchange Trade Documents in Trade Lanes. Master's thesis, Delft University of Technology, 2019.

[41] Konstantinos Christidis and Michael Devetsikiotis. Blockchains and Smart Contracts for the Internet of Things. *IEEE Access*, 4:2292–2303, 2016. doi: 10.1109/ACCESS.2016.2566339.

[42] Blockchain Technology Projects – Hyperledger. URL https://www.hyperledger.org/projects.

[43] Tommy Koens and Erik Poll. What blockchain alternative do you need? *Lecture Notes in Computer Science Data Privacy Management, Cryptocurrencies and Blockchain Technology*, page 113–129, Sep 2018. doi: 10.1007/978-3-030-00305-0_9.

[44] Amit Ganeriwalla, Michael Casey, Prema Shrikrishna, Jan Philipp Bender, and Stefan Gstettner. Does Your Supply Chain Need a Blockchain?, 2018. URL https://www.bcg.com/publications/2018/does-your-supply-chain-need-blockchain.

[45] Gideon Greenspan. Avoiding the pointless blockchain project | MultiChain, 2015. URL https://www.multichain.com/blog/2015/11/avoiding-pointless-blockchain-project/.

[46] ORTEC | Control Tower for Supply Chains. URL https://ortec.com/en/dictionary/control-tower-supply-chains.

[47] SCM Definitions and Glossary of Terms. URL https://cscmp.org/CSCMP/Educate/SCM_Definitions_and_Glossary_of_Terms.aspx.

[48] Davor Dujak and Domagoj Sajter. *SMART Supply Network*. Springer International Publishing, 2019. doi: 10.1007/978-3-319-91668-2.

[49] J. Roland Ortt and Patrick A. Van Der Duin. The evolution of innovation management towards contextual innovation. *European Journal of Innovation Management*, 11(4):522–538, 2008. ISSN 14601060. doi: 10.1108/14601060810911147.

[50] Farhad Panahifar, P. J. Byrne, Mohammad Asif Salam, and Cathal Heavey. Supply chain collaboration and firm's performance: The critical role of information sharing and trust. *Journal of Enterprise Information Management*, 31(3):358–379, 2018. doi: 10.1108/JEIM-08-2017-0114.

[51] Marloes J.T. Claassen, Arjan J Van Weele, and Erik M Van Raaij. Performance outcomes and success factors of vendor managed inventory (VMI). *Supply Chain Management*, 13(6):406–414, 2008. doi: 10.1108/13598540810905660.

[52] G. E. Smith, K. J. Watson, W. H. Baker, and J. A. Pokorski. A critical balance: Collaboration and security in the IT-enabled supply chain. *International Journal of Production Research*, 45(11): 2595–2613, 2007. doi: 10.1080/00207540601020544.

[53] Peter Ralston, R Glenn Richey, and Scott Grawe. The past and future of supply chain collaboration: a literature synthesis and call for research. *The International Journal of Logistics Management*, 28(2), 2017. doi: 10.1108/IJLM-09-2015-0175.

[54] Kuldeep Kumar and Han van Dissel. Sustainable Collaboration: Managing Conflict and Cooperation in Interorganizational Systems. *MIS Quarterly*, 20(3):279–300, 1996.

[55] Qingyu Zhang and Mei Cao. Exploring antecedents of supply chain collaboration: Effects of culture and interorganizational system appropriation. *International Journal of Production Economics*, 2018. doi: 10.1016/j.ijpe.2017.10.014.

[56] Cheng Zhang, Ling Xue, and Jasbir Dhaliwal. Alignments between the depth and breadth of inter-organizational systems deployment and their impact on firm performance. *Information and Management*, 2016. ISSN 03787206. doi: 10.1016/j.im.2015.08.004.

[57] Nir Kshetri. 1 Blockchain's roles in meeting key supply chain management objectives. In *International Journal of Information Management*, volume 39, pages 80–89. Elsevier Ltd, 4 2018. doi: 10.1016/j.ijinfomgt.2017.12.005.

[58] Goknur Arzu Akyuz and Guner Gursoy. Transformation of Supply Chain Activities in Blockchain Environment. In *Contributions to Management Science*, chapter 8, pages 153–175. Springer, 2020. doi: 10.1007/978-3-030-29739-8.

[59] Kaan Unnu, Jennifer A Pazour, and Aly Megahed. Blockchain Enabled Supply Chains : Classification , Decision Framework , and Research Opportunities. 2019.

[60] Saveen Abeyratne and Radmehr Monfared. Blockchain Ready Manufacturing Supply Chain Using Distributed Ledger. *International Journal of Research in Engineering and Technology*, 05 (09):1–10, 9 2016. doi: 10.15623/ijret.2016.0509001.

[61] André Jeppsson and Oskar Olsson. Blockchains as a solution for traceability and transparency. Master's thesis, Lund University, Lund, 2017. URL https://lup.lub.lu.se/student-papers/search/publication/8919957.

[62] Matteo Montecchi, Kirk Plangger, and Michael Etter. It's real, trust me! Establishing supply chain provenance using blockchain. *Business Horizons*, 62(3):283–293, 2019. doi: 10.1016/j.bushor.2019.01.008.

[63] Si Chen, Rui Shi, Zhuangyu Ren, Jiaqi Yan, Yani Shi, and Jinyu Zhang. A Blockchain-Based Supply Chain Quality Management Framework. *Proceedings - 14th IEEE International Conference on E-Business Engineering, ICEBE 2017 - Including 13th Workshop on Service-Oriented Applications, Integration and Collaboration, SOAIC 207*, (November):172–176, 2017. doi: 10.1109/ICEBE.2017.34.

[64] Qinghua Lu and Xiwei Xu. Adaptable Blockchain-Based Systems: A Case Study for Product Traceability. *IEEE Software*, 34(6):21–27, 11 2017. doi: 10.1109/MS.2017.4121227.

[65] Provenance. Blockchain: the solution for supply chain transparency | Provenance. URL https://www.provenance.org/whitepaper.

[66] Hubert Pun, Jayashankar M. Swaminathan, and Pengwen Hou. Blockchain Adoption for Combating Deceptive Counterfeits. *SSRN Electronic Journal*, pages 1–16, 2018. doi: 10.2139/ssrn.3223656.

[67] Richard Adams, Beth Kewell, and Glenn Parry. Blockchain for Good? Digital Ledger Technology and Sustainable Development Goals. In W. Leal Filho, R. Marans, and J. Callewaert, editors, *World Sustainability Series*, pages 127–140. Springer, 2018. doi: 10.1007/978-3-319-67122-2.

[68] V Venkatesh, Kai Kang, Bill Wang, Ray Zhong, and Abraham Zhang. System architecture for blockchain based transparency of supply chain social sustainability. *Robotics and Computer-Integrated Manufacturing*, 63, 6 2020. doi: 10.1016/j.rcim.2019.101896.

[69] Sara Saberi, Mahtab Kouhizadeh, Joseph Sarkis, and Lejia Shen. Blockchain technology and its relationships to sustainable supply chain management. *International Journal of Production Research*, 57(7):2117–2135, 2019. doi: 10.1080/00207543.2018.1533261.

[70] Gabriella M. Hastig and Man Mohan S. Sodhi. Blockchain for Supply Chain Traceability: Business Requirements and Critical Success Factors. *Production and Operations Management*, 29(4): 935–954, 2020. doi: 10.1111/poms.13147.

[71] Nir Kshetri. Can Blockchain Strengthen the Internet of Things? *IT Professional*, 19(4):68–72, 2017. doi: 10.1109/MITP.2017.3051335.

[72] Kristian Lauslahti, Juri Mattila, and Timo Seppälä. Smart Contracts - How will Blockchain Technology Affect Contractual Practices? *ETLA Reports No.68*, 2017. URL https://pub.etla.fi/ETLA-Raportit-Reports-68.pdf.

[73] Brant Carson, Giulio Romanelli, Patricia Walsh, and Askhat Zhumaev. Blockchain beyond the hype: What is the strategic business value? *McKinsey Quarterly*, 2018(4):118–127, 2018.

[74] Usman W. Chohan. The Decentralized Autonomous Organization and Governance Issues. *SSRN Electronic Journal*, 2017. doi: 10.2139/ssrn.3082055.

[75] Stefan Seebacher and Ronny Schüritz. Blockchain-Just Another IT Implementation? A Comparison of Blockchain and Interorganizational Information Systems. *Proceedings of the 27th European Conference on Information Systems*, pages 0–17, 2019. URL https://aisel.aisnet.org/ecis2019_rp/124.

[76] Kangning Zheng, Zuopeng Zhang, Yun Chen, and Jiajin Wu. Blockchain adoption for information sharing: risk decision-making in spacecraft supply chain. *Enterprise Information Systems*, 00 (00):1–22, 2019. doi: 10.1080/17517575.2019.1669831.

[77] Svein Ølnes, Jolien Ubacht, and Marijn Janssen. Blockchain in government: Benefits and implications of distributed ledger technology for information sharing. *Government Information Quarterly*, 34(3):355–364, 9 2017. doi: 10.1016/j.giq.2017.09.007.

[78] Zhaojing Wang, Tengyu Wang, Hao Hu, Jie Gong, Xu Ren, and Qiying Xiao. Blockchain-based framework for improving supply chain traceability and information sharing in precast construction. *Automation in Construction*, 111, 3 2020. doi: 10.1016/j.autcon.2019.103063.

[79] Goknur Arzu Akyuz and Guner Gursoy. Role of management control and trust formation in supply network collaboration. *International Journal of Collaborative Enterprise*, 4(3):137, 2014. doi: 10.1504/ijcent.2014.066320.

[80] Stefan Seebacher and Ronny Schüritz. Blockchain Technology as an Enabler of Service Systems: A Structured Literature Review BT - Exploring Services Science. *Exploring Services Science*, 279(Chapter 2):12–23, 2017. doi: 10.1007/978-3-319-56925-3.

[81] Chris Elsden, Arthi Manohar, Jo Briggs, Mike Harding, Chris Speed, and John Vines. Making sense of blockchain applications: A typology for HCI. In *Conference on Human Factors in Computing Systems - Proceedings*, volume 2018-April, 2018. doi: 10.1145/3173574.3174032.

[82] Johan Pouwelse, Andre De Kok, Joost Fleuren, Peter Hoogendoorn, Raynor Vliegendhart, and Martijn Vos. Laws for Creating Trust in the Blockchain Age. *European Property Law Journal Citation*, 6(3):321–356, 2017. doi: 10.1515/eplj-2017-0022.

[83] D. Harrison McKnight, Michelle Carter, Jason Bennett Thatcher, and Paul F. Clay. Trust in a specific technology: An investigation of its components and measures. *ACM Transactions on Management Information Systems*, 2(2), 2011. ISSN 2158656X. doi: 10.1145/1985347.1985353.

[84] Sebastian Manrique. Blockchain: a proof of trust. Master's thesis, Delft University of Technology, 2018.

[85] Yingli Wang, Jeong Hugh Han, and Paul Beynon-Davies. Understanding blockchain technology for future supply chains: a systematic literature review and research agenda, 1 2019.

[86] Kari Korpela, Jukka Hallikas, and Tomi Dahlberg. Digital Supply Chain Transformation toward Blockchain Integration. In *Proceedings of the 50th Hawaii International Conference on System Sciences (2017)*, 2017. doi: 10.24251/hicss.2017.506.

[87] Niels Hackius and Moritz Petersen. Digitalization in Supply Chain Management and Logistics Blockchain in Logistics and Supply Chain: Trick or Treat? Blockchain in Logistics and Supply Chain: Trick or Treat? *Proceedings of the Hamburg International Conference of Logistics (HICL)*, page 23, 2017. doi: 10.15480/882.1444.

[88] Marten Risius and Kai Spohrer. A Blockchain Research Framework: What We (don't) Know, Where We Go from Here, and How We Will Get There. *Business and Information Systems Engineering*, 59(6):385–409, 2017. doi: 10.1007/s12599-017-0506-0.

[89] Roman Beck, Christoph Müller-Bloch, John Leslie King, and Jason Thatcher. Governance in the Blockchain Economy: A Framework and Research Agenda. *Journal of the Association for Information Systems*, (10):1020–1034, 2018. doi: 10.17705/1jais.00518.

[90] Olivier Rikken, Marijn Janssen, and Zenlin Kwee. Governance challenges of blockchain and decentralized autonomous organizations. *Information Policy*, 24(4):397–417, 2019. doi: 10.3233/ip-190154.

[91] Myo Min Aung and Yoon Seok Chang. Traceability in a food supply chain: Safety and quality perspectives. *Food Control*, 39(1):172–184, 5 2014. doi: 10.1016/j.foodcont.2013.11.007.

[92] Jacques Trienekens, Nel Wognum, Adrie Beulens, and Jack Van Der Vorst. Transparency in complex dynamic food supply chains. *Advanced Engineering Informatics*, 26(1):55–65, 1 2012. doi: 10.1016/j.aei.2011.07.007.

[93] Daniel Bumblauskas, Arti Mann, Brett Dugan, and Jacy Rittmer. A blockchain use case in food distribution: Do you know where your food has been? *International Journal of Information Management*, 2019. doi: 10.1016/j.ijinfomgt.2019.09.004.

[94] Jack Van Der Vorst, Adrie Beulens, and Paul Van Beek. Innovations in logistics and ICT in food supply chain networks. *Innovation in Agri-Food Systems: Product Quality and Consumer*, (January):245–290, 2005. doi: 10.3920/978-90-8686-666-3.

[95] Huub Scholten, Cor Verdouw, Adrie. Beulens, and Jack van der Vorst. Defining and Analyzing Traceability Systems in Food Supply Chains. In *Advances in Food Traceability Techniques and Technologies: Improving Quality Throughout the Food Chain*, chapter 2, pages 9–33. Elsevier Ltd, 2016. doi: 10.1016/B978-0-08-100310-7.00002-8.

[96] Lusine H Aramyan, Olaf Van Kooten, and Alfons Oude Lansink. Performance indicators in agri-food production chains. In C.J.M. Ondersteijn, J.H.M. Wijnands, R.B.M. Huirne, and Olaf Van Kooten, editors, *Quantifying the Agri-Food supply Chain*, chapter 5, pages 47–64. Springer, 2006. doi: 10.1007/1-4020-4693-6.

[97] Lusine H. Aramyan, Alfons G.J.M.Oude Lansink, Jack G.A.J. Van Der Vorst, and Olaf Van Kooten. Performance measurement in agri-food supply chains: A case study. *Supply Chain Management*, 12(4):304–315, 2007. doi: 10.1108/13598540710759826.

[98] F. Verdenius. Using Traceability systems to optimise business performance. In I Smith and A Furness, editors, *Improving Traceability in Food Processing and Distribution*, chapter 2, pages 26–51. Woodhead Publishing, Wageningen, 1st edition, 2006. doi: 10.1533/9781845691233.1.26.

[99] K. M. Karlsen and P. Olsen. *Problems and Implementation Hurdles in Food Traceability*. Elsevier Ltd, 2016. ISBN 9780081003213. doi: 10.1016/B978-0-08-100310-7.00003-X. URL http://dx.doi.org/10.1016/B978-0-08-100310-7.00003-X.

[100] Kine Mari Karlsen, Carl Sørensen, F. Forås, and Petter. Olsen. Critical criteria when implementing electronic chain traceability in a fish supply chain. *Food Control*, 22(8):1339–1347, 2011. doi: 10.1016/j.foodcont.2011.02.010.

[101] Kay Behnke and Marijn Janssen. Boundary conditions for traceability in food supply chains using blockchain technology. *International Journal of Information Management*, page 101969, 6 2019. doi: 10.1016/j.ijinfomgt.2019.05.025.

[102] Cor Verdouw. Business Process Modelling in Demand-Driven Agri-Food Supply Chains. Master's thesis, Wageningen University, 2010. URL https://library.wur.nl/WebQuery/wurpubs/395877.

[103] GS1. What you need to know GS1-The global language of business. Technical report, 2006. URL www.gs1.org/traceability.

[104] Feng Tian. An agri-food supply chain traceability system for China based on RFID & blockchain technology. In *2016 13th International Conference on Service Systems and Service Management, ICSSSM 2016*. Institute of Electrical and Electronics Engineers Inc., 8 2016. doi: 10.1109/ICSSSM.2016.7538424.

[105] Kamanashis Biswas, Vallipuram Muthukkumarasamy, and Wee Lum Tan. Blockchain Based Wine Supply Chain Traceability System. In *Future Technologies Conference (FTC) 2017*, pages 56–62, United Kingdom, 2017. doi: 10.1109/IntelliSys.2017.8324376.

[106] Jun Lin, Zhiqi Shen, Anting Zhang, and Yueting Chai. Blockchain and IoT based Food Traceability for Smart Agriculture. In *Proceedings of the 3rd International Conference on Crowd Science and Engineering - ICCSE'18*, pages 1–6, New York, New York, USA, 2018. ACM Press. doi: 10.1145/3265689.3265692.

[107] Andreas Kamilaris, Agusti Fonts, and Francesc X. Prenafeta-Boldú. The rise of blockchain technology in agriculture and food supply chains. *Trends in Food Science and Technology*, 2019. doi: 10.1016/j.tifs.2019.07.034.

[108] Malvern Chinaka. Blockchain technology-applications in improving financial inclusion in developing economies. Case study for small scale agriculture in Africa. Master's thesis, Massachusetts Institute of Technology, 2016.

[109] Provenance. From shore to plate: Tracking tuna on the blockchain | Provenance, 2016. URL https://www.provenance.org/tracking-tuna-on-the-blockchain#overview.

[110] Reshma Kamath. Food Traceability on Blockchain: Walmart's Pork and Mango Pilots with IBM. *The Journal of the British Blockchain Association*, 1(1):1–12, 2018. doi: 10.31585/jbba-1-1-(10)2018.

[111] Hyperledger. How Walmart brought unprecedented transparency to the food supply chain with Hyperledger Fabric. Technical report, 2018. URL https://www.hyperledger.org/wp-content/uploads/2019/02/Hyperledger_CaseStudy_Walmart_Printable_V4.pdf.

[112] Petter Olsen, Melania Borit, and Shaheen Syed. Applications, limitations, costs, and benefits related to the use of blockchain technology in the food industry, 2019. URL https://nofima.brage.unit.no/nofima-xmlui/handle/11250/2586121.

[113] Maria Caridi, Luca Crippa, Alessandro Perego, Andrea Sianesi, and Angela Tumino. Measuring visibility to improve supply chain performance: A quantitative approach. *Benchmarking*, 17(4): 593–615, 2010. doi: 10.1108/14635771011060602.

[114] Peter Kraljic. Purchasing Must Become Supply Management. *Harvard Business Review*, (September-October):109–117, 1983. ISSN 00178012. doi: 10.1225/83509.

[115] Daniele Asioli, Andreas Boecker, and Maurizio Canavari. On the linkages between traceability levels and expected and actual traceability costs and benefits in the Italian fishery supply chain. *Food Control*, 46:10–17, 2014. doi: 10.1016/j.foodcont.2014.04.048.

[116] Techane Bosona and Girma Gebresenbet. Food traceability as an integral part of logistics management in food and agricultural supply chain. *Food Control*, 33(1):32–48, 2013. ISSN 09567135. doi: 10.1016/j.foodcont.2013.02.004. URL http://dx.doi.org/10.1016/j.foodcont.2013.02.004.

[117] Heineken N.V. Annual Report 2019, 2019. URL https://www.theheinekencompany.com/sites/theheinekencompany/files/Investors/financial-information/results-reports-presentations/heineken-nv-hnv-2019-annual-report.pdf.

[118] Heineken Holding N.V. Annual Report 2019, 2019. URL www.heinekenholding.com.

[119] Ownership structure | The HEINEKEN Company. URL https://www.theheinekencompany.com/investors/governance/ownership-structure.

[120] Jack Buffington and Ray Peterson. Defining a closed-loop U.S. aluminum can supply chain through technical design and supply chain innovation. *JOM*, 65(8):941–950, 2013. doi: 10.1007/s11837-013-0615-2.

[121] Penny Bamber, Stacey Frederick, and Gary Gereffi. The Philippines in the Chemical Global Value Chain. Technical report, Duke University, 2016. URL http://industry.gov.ph/global-value-chain-studies/the-philippines-in-the-chemical-global-value-chain/.

[122] Eric Patton and Steven H. Appelbaum. The case for case studies in management research. *Management Research News*, 26(5):60–71, 2003. doi: 10.1108/01409170310783484.

[123] Michael Gibbert, Winfried Ruigrok, and Barbara Wicki. What passes as a rigorous case study? *Strategic Management Journal*, 29(13):1465–1474, 12 2008. doi: 10.1002/smj.722.

[124] Kathleen M Eisenhardt and Melissa E Graebner. Theory building from cases: Opportunities and challenges. *Academy of Management Journal*, 50(1):25–32, 2007. doi: 10.5465/AMJ.2007.24160888.

[125] Uma Sekaran and Roger Bougie. *Research Methods for Business : A Skill-Building Approach*. Wiley, Chichester, 5th edition, 2010. ISBN 978-0-470-74479-6.

[126] Barbara Farbey and Anthony Finkelstein. Evaluation in Software Engineering: ROI, but more than ROI. In *3rd International Workshop on EconomicsDriven Software Engineering Research (EDSER3) at ICSE*, 2001. URL http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.104.8062&rep=rep1&type=pdf.

[127] Chun Chin Wei, Gin Shuh Liang, and Mao Jiun J. Wang. A comprehensive supply chain management project selection framework under fuzzy environment. *International Journal of Project Management*, 25(6):627–636, 10 2007. doi: 10.1016/j.ijproman.2007.01.010.

[128] Alessandro Brun, Maria Caridi, Kamal Fahmy Salama, and Ivan Ravelli. Value and risk assessment of supply chain management improvement projects. *International Journal of Production Economics*, 99(1-2):186–201, 2006. doi: 10.1016/j.ijpe.2004.12.016.

[129] Maria Caridi, Antonella Moretto, Alessandro Perego, and Angela Tumino. The benefits of supply chain visibility: A value assessment model. *International Journal of Production Economics*, 151: 1–19, 2014. doi: 10.1016/j.ijpe.2013.12.025.

[130] Nicholas Clifford, Shaun French, and Gill Valentine. *Key Methods in Geography*. Sage Publications, Thousand Oaks, CA, 2nd edition, 2010. ISBN 978-1-4129-3508-1.

[131] Susan Jamieson. Likert scales: How to (ab)use them. *Medical Education*, 38(12):1217–1218, 12 2004. doi: 10.1111/j.1365-2929.2004.02012.x.

[132] Geoff Norman. Likert scales, levels of measurement and the ”laws” of statistics. *Advances in Health Sciences Education*, 15(5):625–632, 2010. doi: 10.1007/s10459-010-9222-y.

A

Interview Protocols

A.1. GIS

The goal of this interview to learn about the traceability efforts and capabilities of Heineken. By interviewing people at Heineken Global Information Systems, the aim is to get a good understanding of the IT infrastructure that enables this and what challenges they see in expanding traceability capabilities. This group is also expected to have a good view of blockchain initiatives in and around Heineken and can shed light on the decision making process and their experiences.

A.1.1. Introduction

- The goal of the interview
- Current role, experience, business context

A.1.2. Supply Chain Process

- Could you sketch the Heineken Supply Chain from an information level perspective?
- How is it decided to share certain information?
- How standardized is the information exchange between breweries and partners?

A.1.3. Traceability

- What is your definition of traceability?
- How would you describe Heineken's traceability capabilities, both internally and externally?
- What efforts have been undertaken to increase traceability?
- What are the blocking factors in the current implementation to share more information with supply chain partners to increase traceability?
- Where do you see possible improvements to increase traceability?

A.1.4. Decision Making

- Have you been involved in deciding on blockchain projects?
- How was this decision process organised? (Who were involved etc)
- What were the business cases for these propositions?
- What were the evaluation criteria? What were they based on?

A.1.5. Blockchain Execution

- What has been the overall experience with blockchain pilots?
- What were the benefits?
- What were the challenges?
- Did the team have the necessary knowledge and infrastructure?
- How did you determine which information to share?

A.2. Procurement

The goal of this interview to learn about the traceability efforts and capabilities of Heineken. By interviewing people in Heineken Global Procurement we learn about the characteristics of the different product groups, in terms of requirements, processes and regulations. Furthermore, buyers offer a great opportunity to learn more about the relationship Heineken has with its supply chain partners.

A.2.1. Introduction

- Goal of the Interview
- Current Role, experience

A.2.2. Business Context

- Can you give me a short overview of the business context in which you work?
- Which products are typical for your category?
- What makes your category different to the others?
- Who are the main suppliers and customers for this product?
- Can you give me an overview of the steps of the supply chain process?

A.2.3. Traceability

- What is your definition of traceability?
- What need do you have for traceability? What problems do you currently encounter that can be attributed to a lack of traceability?
- In an end-to-end traceability case, what information would you require from partners?
- In an end-to-end traceability case, what information would you need to share with partners?
- What is the difference between the image depicted in the last two questions and the current reality?
- In an end-to-end situation visible to all actors, what information would you be reluctant to share with others?
- What are the blocking factors in the current implementation to share more information with supply chain partners to increase traceability?
- Where do you see possible improvements to increase traceability?
- What needs to be in place before you can achieve end-to-end traceability?

A.3. External

A.3.1. Introduction

- Goal of the Interview: The goal of these interviews is shed light on the need for and the comparison between blockchain-enabled traceability systems and traditional systems. On what criteria should these systems be compared and how do they then compare? What is the business value of extra visibility and traceability? Which types of problems are better suited for blockchain solutions? And how will societal developments influence the need for traceability?
- Can you tell me more about your current blockchain and traceability projects?

Structure: Introduce business value case shortly and then together develop a set of evaluation criteria for the comparison between implementations. Compare the implementations.

Then build on the business value case, true needs for traceability and the USP of blockchain, societal developments and challenges.

A.3.2. Business Value

- What was the business (value) case for these projects?
- On what criteria do you evaluate your current traceability projects?
- What have been your reasons for developing a blockchain-based system instead of a more traditional solution?
  - What is the difference in visibility (quantity, freshness, accuracy)
  - Criteria Comparison: Suitability, Data Quality, Immutability and Transparency, Confidentiality, Trust, Robustness, Speed and Efficiency, Interoperability
- What is your opinion the state of supply chain visibility in industry, also seeing the current technical and societal developments?
- How has visibility and immutability helped you to make better decisions with regards to supply chain complexity?
- Where is immutability a requirement instead of a nice-to-have?
- What have been the drawbacks of using a blockchain-based system?

A.3.3. Challenges

- What implementation challenges needed to be overcome?
- How granular is your traceability system?
- How do you handle standards issues related to traceability?
- Are there any added costs compared to traditional implementations?

A.3.4. Learnings and Future

- How do current supply chain developments, like agile sourcing, or major disruptions, like COVID-19, change your views and needs for visibility and traceability?
- What are your next steps with traceability and blockchain?

B

Survey

You are being invited to participate in a research study. This study is being done by Declan Buist from the TU Delft in cooperation with Heineken Global Procurement. The topic of the research is technology selection for use in supply chain traceability systems. The technologies are blockchain-based systems or traditional, centralized systems.

First some introductory questions will be asked to determine your blockchain experience. Based on these questions, you will be asked some follow-up questions. Therefore this survey can also be answered by respondents without blockchain experience. Your input will be very valuable.

Your participation in this study is entirely voluntary and you can withdraw at any time. Answering the survey should take no longer than 10 minutes.

We believe there are no known risks associated with this research study; however, as with any online related activity the risk of a breach is always possible. To the best of our ability your answers in this study will remain confidential and responses will be recorded anonomously. For questions, please contact d.j.buist@student.tudelft.nl.

Section A: General Questions

A1. **1. What organization do you work for?**

A2. **2. What is your role?**

A3. **3. How would you rate your experience with blockchain implementation?**

- [ ] Low (No Real Hands-On Experience)
- [ ] Moderate (Few Actual Projects)
- [ ] High (Advanced Knowledge)

Section B: System Characteristics (1)

The purpose of this survey is to understand the difference between blockchain-based and traditional centralized traceability systems for supply chains.

This question is about the judging the importance of the system characteristics below, which can be used to make decisions about technology selection for supply chain traceability systems. The relevance of the characteristics should be independent of the choice of technology.

The context is a global large-scale supply chain with the assumption that the required information can be captured. Therefore both systems can be evaluated solely on their ability to share information.

B1. **4. How important is the criterion when considering blockchain or centralized systems for supply chain traceability use cases?**

	Very Low	Low	Moderate	High	Very High
Suitability	☐	☐	☐	☐	☐
Data Quantity	☐	☐	☐	☐	☐
Data Accuracy	☐	☐	☐	☐	☐
Data Freshness	☐	☐	☐	☐	☐
Data Depth	☐	☐	☐	☐	☐
Integrity and Transparency	☐	☐	☐	☐	☐
Confidentiality	☐	☐	☐	☐	☐
Trust	☐	☐	☐	☐	☐
Robustness	☐	☐	☐	☐	☐
Speed and Efficiency	☐	☐	☐	☐	☐
Scalability	☐	☐	☐	☐	☐
Interoperability with internal ERP/BI Systems	☐	☐	☐	☐	☐
Interoperability with external IT systems	☐	☐	☐	☐	☐

	Very Low	Low	Moderate	High	Very High
Implementation Costs	☐	☐	☐	☐	☐
Operational Costs	☐	☐	☐	☐	☐
Stakeholder Willingness	☐	☐	☐	☐	☐

Section C: System Characteristics (2)

Now respondents are asked to compare the two alternatives based on selected system characteristics.

The characteristics can be judged on a scale evaluating the relative strenght of either implementation to the other. The scale enables judgments indicating strong advantage or moderate advantages for either technology. An answer option is also No Difference, indicating there is generally no significant difference in performance on this characteristic between blockchain systems and centralized systems.

The context is a global large-scale supply chain with the assumption that the required information can be captured. Therefore both systems can be evaluated solely on their ability to share information.

C1. 5. Which implementation is more favourable based on the following criteria?

	Strong Advantage Traditional Systems	Moderate Advantage Traditional Systems	No Difference	Moderate Advantage Blockchain Systems	Strong Advantage Blockchain Systems
Suitability	☐	☐	☐	☐	☐
Data Quantity	☐	☐	☐	☐	☐
Data Accuracy	☐	☐	☐	☐	☐
Data Freshness	☐	☐	☐	☐	☐
Data Depth	☐	☐	☐	☐	☐
Integrity and Transparency	☐	☐	☐	☐	☐
Confidentiality	☐	☐	☐	☐	☐
Trust	☐	☐	☐	☐	☐
Robustness	☐	☐	☐	☐	☐
Speed and Efficiency	☐	☐	☐	☐	☐
Scalability	☐	☐	☐	☐	☐
Interoperability with internal ERP/BI Systems	☐	☐	☐	☐	☐

	Strong Advantage Traditional Systems	Moderate Advantage Traditional Systems	No Difference	Moderate Advantage Blockchain Systems	Strong Advantage Blockchain Systems
Interoperability with external IT systems	☐	☐	☐	☐	☐
Implementation Costs	☐	☐	☐	☐	☐
Operational Costs	☐	☐	☐	☐	☐
Stakeholder Willingness	☐	☐	☐	☐	☐

Section D: Applications

We would like to understand better how certain criteria, that differentiate blockchain from centralized systems, apply to specific use cases.

In the following question, 7 use cases / business objectives have been selected. Respondents are asked how relevant the following four criteria are to this use cases:

Multi-Tier Data Collection: How necessary is it to collect data from higher tier suppliers or distributors in order to reach the business objective.

Trust, but Verify: Do you require more proof than your suppliers assurances to accomplish this business goal, or does this existing trust suffice?

Single, Shared View: The need for multiple actors in the supply chain to have access to the same data on the same time.

Data Sovereignty: Asks you to determine the likelihood that business confidential information will be shared with supply chain partners and therefore the need to be in control of data access and sharing.

A description of the use case can be found by hovering the mouse over the use case (underlined).

This is the final question in this survey. Pressing Submit will end the survey.

D1. 6. Which implementation is more suitable for the following use cases?

	Strong Advantage Traditional	Moderate Advantage Traditional	No Difference	Moderate Advantage Blockchain	Strong Advantage Blockchain
Product Provenance	☐	☐	☐	☐	☐
Improve Sustainability Performance	☐	☐	☐	☐	☐
Improve Operational Efficiencies	☐	☐	☐	☐	☐
Improve Order Fulfillment	☐	☐	☐	☐	☐
Decrease Effect of Product Recalls	☐	☐	☐	☐	☐
Increase Consumer Trust and Satisfaction	☐	☐	☐	☐	☐
Cross Functional Use Cases	☐	☐	☐	☐	☐

	Strong Advantage Traditional	Moderate Advantage Traditional	No Difference	Moderate Advantage Blockchain	Strong Advantage Blockchain
Agile Sourcing	☐	☐	☐	☐	☐
IoT Data	☐	☐	☐	☐	☐

D2. How relevant are these criteria to the listed use cases?Multi-Tier Data Collection

	Very Low	Low	Moderate	High	Very High
Product Provenance	☐	☐	☐	☐	☐
Decrease Impact of Product Recalls	☐	☐	☐	☐	☐
Sustainable Sourcing	☐	☐	☐	☐	☐
Decrease Administrative Workload	☐	☐	☐	☐	☐
Improve Order Fulfillment	☐	☐	☐	☐	☐
Agile Sourcing	☐	☐	☐	☐	☐
Improve Incoming Order Visibility	☐	☐	☐	☐	☐
Track Internal Consumption	☐	☐	☐	☐	☐

D3. How relevant are these criteria to the listed use cases?Trust, but Verify

	Very Low	Low	Moderate	High	Very High
Product Provenance	☐	☐	☐	☐	☐
Decrease Impact of Product Recalls	☐	☐	☐	☐	☐
Sustainable Sourcing	☐	☐	☐	☐	☐
Decrease Administrative Workload	☐	☐	☐	☐	☐
Improve Order Fulfillment	☐	☐	☐	☐	☐
Agile Sourcing	☐	☐	☐	☐	☐
Improve Incoming Order Visibility	☐	☐	☐	☐	☐
Track Internal Consumption	☐	☐	☐	☐	☐

D4. How relevant are these criteria to the listed use cases?Single, Shared View

	Very Low	Low	Moderate	High	Very High
Product Provenance	☐	☐	☐	☐	☐
Decrease Impact of Product Recalls	☐	☐	☐	☐	☐
Sustainable Sourcing	☐	☐	☐	☐	☐
Decrease Administrative Workload	☐	☐	☐	☐	☐
Improve Order Fulfillment	☐	☐	☐	☐	☐
Agile Sourcing	☐	☐	☐	☐	☐
Improve Incoming Order Visibility	☐	☐	☐	☐	☐
Track Internal Consumption	☐	☐	☐	☐	☐

D5. How relevant are these criteria to the listed use cases?Data Sovereignty

	Very Low	Low	Moderate	High	Very High
Product Provenance	☐	☐	☐	☐	☐
Decrease Impact of Product Recalls	☐	☐	☐	☐	☐
Sustainable Sourcing	☐	☐	☐	☐	☐
Decrease Administrative Workload	☐	☐	☐	☐	☐
Improve Order Fulfillment	☐	☐	☐	☐	☐
Agile Sourcing	☐	☐	☐	☐	☐
Improve Incoming Order Visibility	☐	☐	☐	☐	☐
Track Internal Consumption	☐	☐	☐	☐	☐

Thank you for participating in this survey.

If you have any questions, please contact d.j.buist@student.tudelft.nl