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SCHOOL OF BUSINESS, ECONOMICS AND LAW

**MASTER DEGREE PROJECT IN INNOVATION AND INDUSTRIAL MANAGEMENT**

# BLOCKCHAIN INNOVATION IN SUPPLY CHAIN TRACING

*A qualitative multiple-case study on the use of blockchain in supply chain management*


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**BLOCKCHAIN SMART CONTRACTS**
Blockchain smart contracts in supply chain management as a mechanism for trust

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# Abstract

Throughout the history of trade between people and organizations, trust has always been a fundamental requirement. The need for trust increases as supply chain become more global and complex, since trust is handled by an intermediary, this increases the risks which increases the cost of trust. Blockchain is an innovation that is expected to have great impact on the ways we exchange value in the future, especially regarding solving problems of trust. Supply chains are pressured by stakeholders to trace their materials, and blockchain has been pointed out as a solution. The purpose of this thesis is to explore the uses of blockchain technology in supply chain tracing by studying supply chain tracing companies to find out why blockchain is used, what factors makes blockchain a suitable innovation for supply chain tracing and if there are other technologies that can achieve results similar to blockchain.

The study follows a qualitative research strategy to conduct exploratory research in the form of a multiple case study of 5 European supply chain tracing companies using inductive reasoning. Data was collected through semi-structured interview with c-level executives or other professionals at these 5 companies. Study also includes a review on current literature in the field of blockchain technology and blockchain in supply chain management. A thematic analysis was used to answer the two research questions using the collected data as well as current literature on the topic.

The findings of the study suggest that the functions of a chosen blockchain is the most important factor for use in supply chain tracing, especially the immutability which means data cannot be tampered with, which the study found unique to blockchain technology. The immutability allows users to verify data and creates transparency. All these factors together create a system that is proven to work, and that proof makes users trust the technology. Once trust has been built it seems that the actual technical configuration of the blockchain is of less importance to the users, if the system is proven to work, the users do not need to understand how it works. The study also found that the types of blockchains used in supply chain tracing do not have high energy consumption like Bitcoin.



**Keywords:** *Innovation, Blockchain, Supply chain, Supply chain management, Supply chain tracing, Trust, Transparency*

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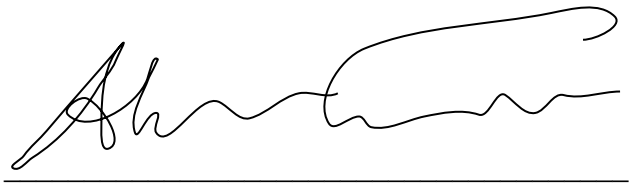

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# Table of Contents

# 1. Introduction

## 1.1 Background

Throughout the history of trade between people and organizations, trust has always been a fundamental requirement (Kehoe et al. 2018). Ever since the invention of money to store value, economies have relied on a trust-based model for trading where a financial intermediary acts as a middleman between the buyer and seller, for example in the form of a bank (Headrick, 2009). As products become more complex, more complex supply chains are needed to produce these products, which put higher requirements on traceability and transparency of information (Kehoe et al. 2018). A supply chain is the network of actors that together enables the process of converting raw materials into a product used by an end customer. Supply chain management is the coordination between one actor in the supply chain, with the other actors. This can be both upstream, coordinating with a previous stage in the supply chain, or downstream, coordinating with a later stage in the supply chain. The goal of supply chain management is to maximize added value while minimizing costs. (Simchi-Levi et al. 2021)

Innovation of technological solutions are set to solve these problems, as if a technical solution could provide the function of trust for digital interaction between parties, intermediators may not be needed, which would leave the trust-based model in favor for a new model for trading (Mattila, 2016). Blockchain is a technology that is expected to have great impact on the ways we exchange value in the future, especially regarding solving problems of trust and may be as disruptive as the creation of the internet (Warburg, 2016). Even though the paper-based documents used in supply chain today is used to increase for example traceability, trust is still required as there is a possibility to alter the information on paper-based documents, here blockchain might have the potential to allow interaction and relationship building even when there is no trust (Wüst & Gervais, 2017). World Economic Forum estimates that by the year 2025, 10% of the gross domestic product of the entire world will use blockchain to store value (Bauman et al. 2016). As companies are becoming more internationalized and more complex, so do their supply chains, and trust and traceability is a big issue, but blockchain might be a potential solution (Kamath, 2018). Kamath (2018) studied the case of Walmart which is a well-documented case for blockchain in the food industry, characterized by a complex global supply chain.

When a supply chain is complex and globally distributed there is often a lack of transparency and traceability and there is usually not a system in place to trace a product throughout a global supply chain (ElMissiry & ElMissiry, 2018). Regulations and standards in modern contexts often require companies to attest to the quality and origin of a product which requires transparency and traceability throughout the supply chain (Challener, 2014). There is also an increasing pressure from stakeholders for companies to use a sustainable approach to sourcing materials (Huq & Stevenson, 2020). In industries with high requirements for transparency and traceability, where a complex supply chain also is present, blockchain could be a solution to these issues (ElMissiry & ElMissiry, 2018). This sparked the interest to study how blockchain technology is currently being used for supply chain tracing, if there are other technologies that can achieve similar results, and what implications the use of blockchain has for the environmental impact of supply chains.

It is common to hear people refer to some specific piece of information, transaction or application as being on "the blockchain" in the same way as people refer to information being on "the internet" (Laurence, 2017), where the internet is globally interconnected networks that can all be reached through the world wide web (Stewart, 2000), which sounds like everything on "the blockchain" is being part of the same network, and while the are some massive blockchains like Bitcoin with a great number of people on the same network, there is no "one blockchain" as in all applications using blockchain technology being connected to the same network like the internet, rather it is common to create many different and completely separated blockchains which are created with the functionality to serve specific business problems (Laurence, 2017). In other words, unlike the internet, blockchain is not a globally interconnected network, and there is no world wide web to access all blockchains, although some blockchains like Bitcoin and Ethereum, happen to be globally interconnected since they have users from all over the world.

## 1.2 Problem Discussion

Even though trade has become more digitalized with transactions over the internet, it still uses the same trust-based model. Here financial institutions serve as a trusted third party to mediate between the buyer and the seller. Even though this model works for most transactions, there is still a risk of fraud, which all parties accept as a risk in doing business. By replacing the trust-based model with cryptographic proof of the transaction, both the need for trust between buyer and seller, and the need for a financial intermediary, would no longer be necessary. Instead, transactions could be handled peer-to-peer with cryptographic proof. Using blockchain, a transaction is stored on a block that builds on the information of the previous block and to maintain the link between the blocks, the information cannot be altered. (Nakamoto, 2009) This means information can be traced back through the blockchain and ensures trust and security since the information cannot be altered.

Blockchain technology could be used as an open and transparent way to store contracts digitally, where the contracts can be viewed by anyone but still cannot be altered or deleted. Information regarding the agreements, the transaction and the payments can all be stored in a shared database on the blockchain. This also makes it possible for parties to trade peer-to-peer without the need for financial intermediaries. (Iansiti & Lakhani, 2017)

Supply chains in globally distributed industries like food and pharmaceuticals are often complex (Dabbene et al. 2014). When a supply chain is complex and globally distributed there is often a lack of transparency and traceability and there is usually not a system in place to trace a product throughout a global supply chain (ElMissiry & ElMissiry, 2018). Regulations and standards in modern contexts often require companies to attest to the quality and origin of a product which requires transparency and traceability throughout the supply chain (Challener, 2014). There is also an increasing pressure from stakeholders for companies to use a sustainable approach to sourcing materials (Huq & Stevenson, 2020). In industries with high requirements for transparency and traceability, where a complex supply chain also is present, blockchain could be a solution to these issues (ElMissiry & ElMissiry, 2018).

Despite the many potential uses for blockchain in different industries, most research is focused on technology and finance, and more specifically Bitcoin is the most researched topic, accounting for 80% of the research that has been conducted within the field of blockchain (Yli-Huumo et al. 2016). The research on other uses of blockchain is however still limited and within supply chain tracing there is a lack of proven use cases, and more research is required, within transparency of supply chain management research is scarce (Hughes et al. 2019).

## 1.2 Purpose and Research Question

The purpose of this thesis is to explore the uses of blockchain technology in supply chain tracing by studying supply chain tracing companies to find out why blockchain is used, what factors makes blockchain a suitable innovation for supply chain tracing and if there are other technologies that can achieve results similar to blockchain for supply chain tracing. The study aims to provide a deeper understanding of what implications the current and future uses of blockchain technology in supply chain tracing might have for further research in the field of blockchain technology by studying how and why blockchain technology is used in supply chain tracing. The purpose of exploring the uses of blockchain technology in supply chain tracing to provide further research in blockchain technology results in the following two research questions:

***Research Question 1: What factors makes blockchain a suitable innovation for supply chain tracing?***
***Research Question 2: What other technologies achieve results similar to the use of blockchain for supply chain tracing?***

## 1.3 Delimitations

Even though most research within blockchain has been done on Bitcoin, Bitcoin will not be included as this study will explore other uses of blockchain. Bitcoin is however one of the first successful uses of blockchain technology and the paper written by Satoshi Nakamoto (2009) will be used to explain the blockchain technology. This study will also specifically explore ways to use blockchain technology within supply chain management, and it will specifically look at what impacts the use of blockchain has on supply chain tracing. Even though stakeholders pressuring companies to be more sustainable is a driving factor for increasing transparency and traceability, sustainability is not the main focus of this study, the effect on sustainability in terms of environmental impact will only be studied as one of several reasons blockchain is used. Further this study will not include any legal aspects of implementing blockchain technology. The study will be limited to the study of software-focused companies offering supply chain tracing services in terms of industry and only companies based in Europe in terms of geographical scope. Other companies and other geographical segments will not be taken into consideration. The study is also limited to companies that are already using services based on the use of blockchain technology. There are limitations to time and resources since the study will be conducted by a single researcher over the span of four months, this will limit the possible number of interviews executed for this study. The expertise needed for the interviewees will further limit the number of interviews since knowledge in the technical aspects of blockchain is a very niche area of expertise. Since the study is executed over this short time span, it will examine the situation regarding the companies' use of blockchain at the time of the study, it will not follow any company over time to study an implementation process or changes over time.

## 1.4 Disposition

The study is structured into the following six chapters: The introduction, the theoretical framework, the methodology, the empirical findings, the analysis, and the conclusion.

The introduction includes the background to the study, followed by the problem discussion, purpose statement, and research questions. The theoretical framework explains the theory of supply chain management and blockchain technology that the study will build upon. The methodology section explains the reasoning behind all design choices made for the study. The empirical findings summarize the results of the primary data collection. The analysis is aimed at using the theoretical framework to explain the empirical findings. The conclusion ties the concluding remarks of the analysis back to answering the research questions as well as provides suggestions for further research.

# 2. Theoretical Framework

## 2.1 Introduction to Trust in Trading

Trust has always been a fundamental requirement for trading between people and organizations (Kehoe et al. 2018). Ever since the invention of money to store value, economies have relied on a trust-based model for trading where a financial intermediary acts as a middleman between the buyer and seller. The first institutional banks as financial intermediaries were responsible for storing money as well as loaning and lending for interest, for which the conditions were backed by law. As the printing of fiat money was invented, there is a need for the public to trust a central bank to control the inflation of the currency. Other examples of financial intermediaries include insurance companies, mutual funds, stock exchanges and escrow companies. (Siklos, 2001). All of these examples can be seen as being based on the same trust-based model where an intermediary acts as a third party between the seller and buyer as shown in Figure 1 below.


*Figure 1. The Trust-based Model for Trading with an intermediary.*

## 2.2 Innovation in the Trust-based Model

The creation of insurance companies, mutual funds, stock exchanges and escrow companies are all examples of innovation in the trust-based model as the development of markets require more trust-based services. Despite this, trust can become an issue when companies become more internationalized and complex, as they require more complex and globally distributed supply chains. (Kamath, 2018). Trust also becomes a bigger issue in digital environments in the sense that it may be difficult to know if the other party will deliver what they promise or even are who they say they are when parties are unknown to each other. Currently there are financial intermediaries offer the role of facilitating trust between parties, and trust may have a high price, which means intermediaries can charge high fees (Mattila, 2016). In other words, the cost of trust is high, and without financial intermediaries trading comes with high risks in complex global and digital environments. Innovation of technological solutions are set to solve

these problems, as if a technical solution could provide the function of trust for digital interaction between parties, intermediators may not be needed, which would leave the trust-based model in favor of a new model for trading (Mattila, 2016). Blockchain for example, is a technology that is expected to greatly impact the ways we exchange value regarding solving problems of trust (Warburg, 2016; Kamath, 2018). Since blockchain replaces the need for trust by cryptographic proof (Mattila, 2016), it might have the potential to allow interaction and relationship building even when there is no trust (Mattila, 2016; Wüst & Gervais, 2017). This has interesting implications for how intermediaries create value in the future, since intermediaries capitalize on the lack of trust, which might not be an issue in the future (Mattila, 2016).

## 2.3 Supply Chain Management

Supply Chain Management is the management of the supply chain, where a traditional supply chain can be described as the flow of materials and processes to create products from raw materials and includes the suppliers of materials and components, the production in a factory, the shipping to a warehouse, the shipping to a retailer, and the shipping to a consumer (Simchi-Levi et al. 2021). The term Supply Chain Management is defined as quoted by Simchi-Levi et al (2021) p.1:

> "Supply chain management is a set of approaches utilized to efficiently integrate suppliers, manufacturers, warehouses, and stores so that merchandise is produced and distributed at the right quantities, to the right locations, and at the right time, in order to minimize systemwide costs while satisfying service level requirements." (Simchi-Levi et al. 2021)

The goal of supply chain management is to maximize added value while minimizing costs, trends of increasing competition, higher customer expectations, shorter product life cycles, and new risks like cybersecurity and the covid pandemic, forces supply chain management to evolve, while there are also challenges of managing new technology (Simchi-Levi et al. 2021). There is an increasing concern among customers to know the origin of the products they buy and to ensure they are authentic, as well as transparency of transactions (Loop, 2017). This is especially true and in food following the debate on GMO and labels, Loop (2017) uses the example of fish, where customers want to know if the fish is farm-raised or if it is sustainably

caught. The factors that are driving the digital transformation of supply chain management is a need for more information that is secure, authentic and immutable for the purchase process, consumers expect transparency of the supply chains that delivers the products they buy, more software companies that help brands motivate sourcing goods in ethical and sustainable ways, and that blockchain is already being used in the finance and insurance industries (Loop, 2017).

## 2.4 Blockchain Technology

One simplified definition of Blockchain technology is that it is a type of distributed database, although the technology is rather the way the data is stored in the database, using the computers connected to the network to audit and solve a cryptographic problem to encrypt and store data into blocks that are chained together making the information stored in the database permanent, and content cannot be changed (Laurence, 2017). The most popular description of blockchain technology is however the one written by Nakamoto (2009) in the white paper for Bitcoin, which is also the most studied blockchain (Yli-Huumo et al. 2016) and is the following description: In the traditional trust-based model for trade, a trusted third party like a financial institution usually acts as a mediator between the buyer and seller. This model helps to increase trust between the trading parties but cannot prevent fraud or manipulation of documents (Nakamoto, 2009). Replacing the trust-based model with cryptographic proof of the transaction means no trust between buyer and seller and no financial intermediary is needed, instead, transactions could be handled peer-to-peer with cryptographic proof. Using blockchain, a transaction is stored on a block that builds on the information of the previous block and to maintain the link between the blocks, the information cannot be altered (Nakamoto, 2009). When a member of the blockchain network makes a transaction, it is sent out as a request that needs to be verified by the other members of the network, the members of the network are called nodes and lend their computer power to solve a cryptographic problem used to verify and encrypt the transaction as well as a connection to the previous block and by that creating a new block on the blockchain and completing the transaction (PwC, n.d.). Every node, meaning everyone connected to the same blockchain network, has the same identical copies of the entire blockchain, and it is constantly shared and updated with each new block, and with the security increasing with each new block as well as each new node in the network, blockchain stores and shares data with much higher security than any other form of database (Walport, 2016). The code for the computer program that was built to run the Bitcoin blockchain technology is open source, which means the access to the code is free and open for anyone to use it to build their

own applications using blockchain, which has helped the blockchain technology to spread (Bauman et al. 2016).

Although there are already many people that have developed an understanding of what blockchain technology is, and also adopted using blockchain in the form of Bitcoin (Yli-Huumo et al. 2016), there are still people referring to some specific piece of information, transaction or application as being on "the blockchain" in the same way as people refer to information being on "the internet" (Laurence, 2017), where the internet is globally interconnected networks that can all be reached through the world wide web (Stewart, 2000), this sounds like everything on "the blockchain" is being part of the same network, but there is no "one blockchain" as in all applications using blockchain technology being connected to the same network like the internet, while the are some massive blockchains like Bitcoin with a great number of people on the same network, it is rather common to create many different and completely separated blockchains which are created with the functionality to serve specific business problems. (Laurence, 2017) Blockchain is not a globally interconnected network, and there is no world wide web to access all blockchains.

Walport (2016) reports that since blockchains are not governed, they are used in unregulated markets and even for transactions directly related to crime, and that other reasons for using blockchain for these purposes in particular could be that parties want to trade anonymously and not be held accountable for their actions. Cryptocurrency like Bitcoin has had a history of being widely used in black-market transactions which has given both Bitcoin, cryptocurrency and blockchain technology in general, a bad reputation as being created for illegal black-market transactions, and also a belief that using blockchain is untraceable for illegal activities, cryptocurrencies are however simply currencies for allowing digital peer-to-peer transactions, and are by themselves not responsible for the black-market transactions that has been made (Laurence, 2017). It is also not correct that cryptocurrency trades are untraceable, the ledger is public, and all transactions are traceable, from using currencies like USD to trade for cryptocurrency, to illegal transactions being done, what was purchased, and cryptocurrency moving to the seller, and being exchanged for cash (Laurence, 2017), and this can be done for all transactions, whatever the purpose of the transaction may be, and the records are permanent.

Blockchain technology offers increased transparency, tracking possibilities, permanent records of transactions and reduced cost by automation and removal of financial intermediaries (PwC, n.d.). Most people tend to think of blockchain technology as a means of transferring value and indeed most of the applications of blockchain is within financial services (Laurence, 2017), and specifically cryptocurrencies like Bitcoin, since peer-to-peer transactions without intermediaries was the purpose of its creation (Nakamoto, 2009). However the characteristics of blockchain, the high security of blocks of information, that the data stored is verifiable and that the data records are permanent, also lends the technology well to some other interesting potential application areas where there is a need for secure storage of sensitive data, this can be used as a way of encrypting patient information and medical records within healthcare, this includes medical history, social security numbers and insurance information, which may need to be shared with other departments, other hospitals, pharmacies, use for referral and insurance companies, by connecting all parties that need the information to a blockchain, it will allow all parties secure access to the information they need, while it remains private to the outside world (Laurence, 2017). Blockchain could also be used for handling the voting process in elections and also apply an automated counting of votes and immediate verification of results (PwC, n.d.). Other potential uses include using blockchain for managing shared ownership of cars (PwC, n.d.), but also by banks for automatic clearing, and insurance companies for automating settlement processes (PwC, n.d.). Blockchain redefines perceived trust in a digital setting by removing the need trust any single member of a network, this makes trading with strangers easier and safer, the only form of trust needed is that there is no colluding between a majority of the network against other members, and decentralization protects the network from single points of failure, this may be called a form of "digital trust" (Mattila, 2016). Blockchain is a collaborative technology that can lower the cost of trust and can also be seen as a new technological software approach for improving business processes, both internally and when companies are trading with each other (PwC, n.d.). Since blockchain has the potential of lowering costs by automating processes, the return on investment in blockchain for companies might be higher than traditional internal investments in improving business processes (PwC, n.d.). The high security of blockchain is expected to reshape online security entirely and technology analysts are already discussing in which ways, all in all blockchain will be of great importance and have high influence on how business is done by everyone in the future (Laurence, 2017).

Zhao et al. (2017) describe digital currency like Bitcoin as the first generation of blockchain, but as more applications are created on the blockchain, there are new generations of blockchain, namely Blockchain 2.0 for digital finance, and Blockchain 3.0 for digital society, and is believed to potentially revolutionize fields like finance, accounting, management, and law. Even though they are considered different generations, Blockchain 2.0 and 3.0 have rather emerged at the same time in parallel, then one after the other. Blockchain 2.0 and 3.0 have not yet displayed an economic impact in the way Blockchain 1.0 has with Bitcoin, but the number of experimental projects is increasing at a fast pace (Zhao et al. 2017). Since supply chains have other uses for blockchain than the digital currencies of blockchain 1.0, it will be more focused on Blockchain 2.0 and 3.0.

### 2.4.1 Challenges in using Blockchains

There are also challenges with using blockchain, since it is very difficult to remove information from the blockchain, there is an issue if legal actions or privacy regulation requires information to be removed, it is difficult to handle these issues on a public blockchain since the technology prohibits any form of model of governance to be applied. Different blockchains support different functions, which means a company may need to use several blockchains for different functions that cannot be integrated with each other, there is also a problem with the cryptographic verification model proof-of-work used today in that it is inefficient and very energy consuming, all copies of the blockchain also require a lot of storage space (Simchi-Levi et al. 2021). The two main types of applications for blockchains are public, permissionless, business-to-consumer (B2C) blockchains using cryptocurrency, and private, permissioned, business-to-business (B2B) blockchain that can be used for tracking goods as an example. The two most popular blockchains, Bitcoin and Ethereum, are both examples of the public, permissionless, B2C blockchains with attached cryptocurrencies, that anyone can join. These are however not well suited for business-to-business application since transactions are not confidential and the validation is slow and costly (Simchi-Levi et al. 2021).

Although much publication is focused on the application of blockchain technology, blockchain has also been met with some skepticism. One aspect of blockchain skepticism is regarding how it will affect accounting, since accounting fills a role of assurance that the blockchain would replace, but since regulations require auditing, the question is raised how an accountant would be able to audit a blockchain and whether the accountant would audit the transaction on

a blockchain, or the entire blockchain itself, and if the accountant is supposed the blockchain itself, there is the question of how much the accountant would need to understand on a technical level to be able to audit the blockchain (Ovenden, 2017). The blockchain technology is however in to early of a stage to know what effect it will have on accounting as there is a need for regulators to understand the technology first, it may take 10 years until the impact of blockchain technology is visible, and it has yet to reach even an adoption from the wider mainstream (Ovenden, 2017).

### 2.4.2 Blockchain Regulation

Blockchain might also cause changes in law and regulation, since digital value transfer has always required a financial intermediary, it has been easier to indirectly govern digital value transactions by regulating the financial intermediaries (Mattila, 2016). These regulations will however not be applicable in peer-to-peer blockchain value transfer, which may require a new approach where there is regulation on computer code, and in this case the transparency and automatization in blockchain might aid regulators. Other benefits include using blockchain smart contracts for automating taxes and tariffs by including regulators in the supply chain blockchain networks (Mattila, 2016).

### 2.4.3 Permissionless and Permissioned Blockchains

Access to the data on a blockchain can be either permissionless, where anyone on the network can view the data, or permissioned, where permission is needed to view the data (Arsov, 2017). A permissionless blockchain cannot have an owner, the data is public, anyone can join the network as nodes, and all nodes in the network are used to reach consensus and form new blocks, which creates high security, Bitcoin is an example of this (Nakamoto, 2009). A permissioned blockchain has one or several owners that can control who is able to access the blockchain and may use other ways to reach consensus to make the process simpler, faster and require less power (Arsov, 2017). However, using less nodes or less computational power to reach consensus in turn makes the blockchain less secure against an attacker, and this is because an attacker needs to have higher computational power than what is used to create the blocks (Nakamoto, 2009). Theoretically, if one single node controls at least 51% of computational power of a blockchain it could dominate the network like a majority vote, so in this case this major node could alter the history of the blockchain without needing other nodes to reach consensus and validate the changes (Yli-Huumo et al. 2016). There are also hybrid forms of

permission, like a consortium blockchain where creation of new blocks is controlled by a select number of nodes, and the right to view the blockchain may be either public or private (Arsov, 2017). Private, permissioned blockchains are usually used internally by organizations, where all participants are known, it can however be questionable if these should truly be considered as blockchains (Bauman et al. 2016). Private permissioned blockchains are also used by governments and financial institutions, one example is Linq, created by Nasdaq for trading unregistered securities (Bauman et al. 2016).

## 2.5 Blockchain Smart Contracts

Blockchain is not a technology that works by itself, rather it allows applications to be run using blockchain technology, and one of these applications that has significant implications for use in business is smart contracts (Nowiński & Kozma, 2017). Smart contracts are defined as (Capgemini, 2017, p.1) "*programmable contracts that automatically execute when pre-defined conditions are met*". Smart contracts are part of what Zhao et al. (2017) refer to as digital finance and Blockchain 2.0 and can be used on both distributed and non-distributed ledgers (Capgemini, 2017), meaning they can be used on both public, permissionless, B2C blockchains as well as private, permissioned B2B blockchains (Simchi-Levi et al. 2021).

Smart contracts on Blockchain are not reversible, and have high immutability and security and guaranteed execution, the terms are programmable and both parties sign the contract, it can also lock funds as escrow services, and when the conditions are met the contract executes automatically (Capgemini, 2017). Smart contracts may impact a company's bottom line, reducing administration and service costs and help with compliance, record keeping, and manual intervention by automating business processes. Smart contracts saves time and prevent delays caused by sending documents between parties, and they also lower costs since no fees for services of financial intermediaries are needed (Capgemini, 2017).

Smart contracts with features like multi-signature payments, escrow services, are already in use today (Capgemini, 2017). There are however challenges with using more complex smart contracts, including that there is a need for interoperability to integrate the smart contracts with the company's IT systems, in some instances both parties might agree to changes in the contract, which is not possible to change in current smart contracts, they also cause human capital challenges, as companies might need lawyers that can program smart contracts, there

may also be a privacy issue as contract will be viewable to all members of the used blockchain as well as a governance issue as to ownership and access to data and what transactions are allowed, all these challenges may push back the adoption of smart contracts a several years but the time depends on how these challenges are handled and many companies are already experimenting (Capgemini, 2017).

## 2.6 Blockchain in Supply Chain Management

There are already many goods, from electronic devices to art pieces, that have different forms of digital markers that could be used to track the items, but there is still a need for solutions to track these items globally and there is also a need for a solution that offers control of permission of who can see and access the information. Within supply chain there is still heavy use of documents in paper form that serves as proof for the origin and handling of a production throughout the supply chain. There is however a problem with this method as paper documents can be altered or even forged entirely. These problems could be solved by using a distributed ledger or database that is shared among the parties in the supply chain, which could also utilize digital signatures from all parties handling the product. Blockchain technology could be a way to supply these needed functions, allowing all parties to digitally sign documents and contracts using a private key, which includes automatic time stamps of the exact time and date of each step throughout the supply chain, which increases the reliability of the whole process. All this information could also be made available for a retailer selling the product to its customers and other stakeholder as proof of the origin and handling of a product which could help them prove sustainability in the sourcing of the products they sell. (Walport, 2016) If the sourcing and handling of a product is proved sustainable throughout the supply chain, this could impact the brand image positively for all parties involved in the supply chain to all of their respective shareholders. (Loop, 2017).

There is potential in blockchain technology to change how systems for supply chain management are built, implemented, and used, along with the benefits of decentralization (Loop, 2017). The benefit of decentralization is that a blockchain cannot be corrupted since all parties have a copy of the same blockchain and there must be a consensus to make a change to block in the chain, which means it offers high cybersecurity, and the consensus model eliminates the requirement of trust between parties which in turn eliminated the need of a third-party financial intermediary (Simchi-Levi et al. 2021). As products become more complex, more complex supply chains are needed to produce these products, which put higher requirements on traceability and transparency of information (Kehoe et al. 2018). Blockchain technology has some implications regarding transparency in supply chains, especially when a public blockchain is used, as all transactions throughout the supply chain is visible to all parties in the supply chain, and also to the public, so anyone that has an interest can view the transactions, also everyone has the same ledger so no information can be altered without the agreement of all parties. (Simchi-Levi et al. 2021). Even if a private blockchain is used, it can be made to provide transparency to all parties within the supply chain, but not to the public outside the supply chain (Bauman et al. 2016). Blockchain in supply chain can improve transparency by keeping track of the origin of food, how it has been handled, and the environmental impact (Loop, 2017). There are use cases where blockchain is used to trace the handling of a product as it moves through the supply chain. Walmart has used a Hyperledger framework developed by IBM called Fabric, to trace imported food like mangoes and pork meat. Target is working on implementing a similar blockchain solution using the competing Sawtooth framework by Intel. (Simchi-Levi et al. 2021). This kind of transparency shows consumer that a brand holds themselves accountable, which could increase trust and loyalty to a brand, and some companies like the canned fish producer John West already see it as a competitive advantage to increase sales, since the information is on blockchain, John West can use the technology to prove that the information cannot be altered which increases trust (Simchi-Levi et al. 2021). This can also help in detecting counterfeit products, since a record is kept on all authentic products, the traceability of the blockchain could help in recovering stolen goods and the requiring all parties to confirm a transaction before it takes place could help prevent fraudulent transactions by holding funds until all conditions are met, and this can be done by using smart contracts (Simchi-Levi et al. 2021). This may also have an interesting effect on balance of power in supply chain networks: When supply chains are not transparent, companies can make many decisions without involving the customer, but as supply chains

become more transparent customers can demand more detailed information and influence companies' supply chain decisions (Mattila, 2016).

Even consumers could potentially utilize smart contracts to customize production processes to meet their preferences regarding what materials are used or how sustainable the process is by buying from manufacturers directly instead of retailers (Mattila, 2016). A customer could put out an order and the smart contract could automatically choose the manufacturer most optimized to the specifications (Mattila, 2016). Smart contracts also have interesting implications for machine-to-human and machine-to-machine contracts which could create new business models, Mattila (2016) gives the example of efficient automatically adjusting allocation of resources for autonomous distributed markets, and autonomous wealth accumulation for individual components to cover their own costs.

Since transactions are not confidential on public and permissionless blockchains like Bitcoin and Ethereum and the validation is slow and costly they are not well suited for B2B or supply chain applications. There are private blockchains that are being used in commercial settings used for various purposes with different trust mechanisms and different rules, but that is in closed communities and usually internally within an organization, but these blockchain often lack interoperability with one another with makes them hard to scale, and also hard to use in complex supply chains since there will be many parties that need different functions from different blockchains that are not interoperable (Walport, 2016). To create blockchains better suited for B2B and supply chain, The Linux Foundation started an open-source project with Intel and IBM called Hyperledger on with B2B blockchain solutions can be built as private, permissioned network for confidential transactions and a faster validation mechanism. Both the Fabric framework by IBM and the Sawtooth framework by Intel are built on Hyperledger, there is also collaboration projects like Burrow, that allows running Ethereum smart contracts feature from Ethereum on a Hyperledger blockchain. (Simchi-Levi et al. 2021)

In business applications of blockchain the parties are usually known and permissioned, as opposed to the public blockchains that are permissionless and can be used by consumers, this allow these permissioned blockchains to use simpler and less costly mechanisms for approval of transactions. IBM has developed a blockchain-based platform for tracking shipments globally called TradeLens that is now used in shipping by Maersk. IBM has also created several other supply chain blockchain projects like The Food Trust Chain with 10 big food

companies to track food throughout its supply chain globally, and the Trust Your Supplier network with Chainyard for buyer and supplier relations. The company Everledger created a blockchain registry to verify and track diamonds and the company SAP uses a low-cost, simplified blockchain for pallet data. (Simchi-Levi et al. 2021) TE-FOOD is the world's biggest food tracing blockchain solution that has a reach of 150.000 people and handles 400.000 transaction per day (TE-FOOD, 2022).

## 2.7 Connection to Internet of Things

The Internet of Things (IoT) has been defined by Internet of Things Global Standards Initiative as *"A global infrastructure for the information society, enabling advanced services by interconnecting (physical and virtual) things based on existing and evolving interoperable information and communication technologies."* (ITU, 2015, paragraph 3.). Utilizing a decentralized model for IoT devices could be a way for manufacturers to lower the costs of maintenance of for example distributing software updates to millions of devices even after the devices have been discontinued, and blockchain for IoT could be a way to automate data collection and software updates (Christidis & Devetsikiotis, 2016). As more and more products and devices are able to produce data and communicate with each other the IoT lend itself well to be used in blockchain applications like smart contracts that are carried out automatically when specific conditions are met, like transferring money when a product is delivered (Simchi-Levi et al. 2021). Another example is if a manufacturer operate all IoT devices on a blockchain and all devices are shipped with a built-in smart contract that automatically updates the device when a new software update is available, automatically updating the whole network, but what is interesting is that once the update is distributed, it is left on the network even if the manufacturer leaves the network, allowing new devices to receive the update from previously updated devices instead of directly from the manufacturer, solving the problem of keeping updates available for discontinued devices (Christidis & Devetsikiotis, 2016). IoT on blockchain in the energy sector can create peer-to-peer markets where in the example of the company TransActive Grid in New York, solar panels automatically sell excess energy produced back to the grid using blockchain transactions, and automatically buy energy from a neighboring party when it does not produce enough by itself (Christidis & Devetsikiotis, 2016).

A potential supply chain example of IoT Blockchain is in container shipping is that a container usually moves through different shipping companies by train, boat and truck, these companies

usually have their data in their own databases (Christidis & Devetsikiotis, 2016). By using blockchain they could all share the same network and add shipping information along the journey of the container and even tie the information into a smart contract that actives upon arrival, and also acts as an immutable receipt that the container was delivered. This could also make use of a token model, where a token signaling one party has received the container physically, and also the legal responsibility, and this token moves through transactions between the shipping companies as the container moves and if both the container and the people handling the container have radios that communicate with each other and the blockchain without user input, transactions can be done automatically like on an IoT blockchain and also contain a timestamp to avoid disputes of responsibility and delays (Christidis & Devetsikiotis, 2016).

The combination of the decentralized, trustless, peer-to-peer functions of blockchains, the automation possibilities of smart contracts, and the use of IoT devices as physical points of contact, allows for automation of time-consuming workflows which saves time and money and offers high security with the distributed ledger and the immutability of the cryptographic verification. This phenomenon has the potential to both create new business models, systems, and processes, and to transform entire industries (Christidis & Devetsikiotis, 2016). There are however challenges with IoT blockchains, if using the proof-of-work model, verifications of new blocks become slower as more nodes are added to the network as consensus are needed which creates a problem with scalability since the number of transactions in a given timeframe are limited (Christidis & Devetsikiotis, 2016). This could however be solved by using permissioned blockchains to limit the number of nodes needed for verification to make the process simpler, faster and require less power (Arsov, 2017), though using less nodes to reach consensus has the trade-off of lowering security against attackers, since an attacker control of the majority of the computational power on the network (Nakamoto, 2009; Yli-Huumo et al. 2016). Another limiting factor is the privacy aspects, since the blockchain technology builds upon transparency (Christidis & Devetsikiotis, 2016), there may however be solutions to this by using permissioned blockchains as well (Arsov, 2017). Since there is a lack of regulation on blockchain and smart contracts, the is a limited Legal enforceability of smart contracts is limited, a solution to this could be to tie the smart contract to a real-world, legally valid contract (Christidis & Devetsikiotis, 2016). There is also a problem with smart contracts in that if you wish to free up funds that are locked in a smart contract, that may not be possible if that option

is not added to the contract, but that also defeats the purpose of locking funds as a trust-mechanism (Christidis & Devetsikiotis, 2016).

## 2.7 Synthesis of Theory

To synthesize the theory, a blockchain appears to be made up of a combination of several factors, and there are different ways to structure each factor. In terms of the blockchain type, consensus mechanism, and method of access, one alternative of each factor is chosen and theoretically any combination should be possible. Regarding the Functions that a specific blockchain offers, it depends on what applications are built on the blockchain and what functions those applications support, like Smart contracts and connection to IoT. Some functions are however fundamental to any blockchain, like that the ledger is distributed, and that the information recorded on the blockchain is immutable and permanent. Table 1 below shows the different functions, types, consensus mechanisms, and methods of accessibility found in the literature.

| **Blockchain Functions** | **Blockchain Types** | **Consensus Mechanisms** | **Accessibility** |
|---|---|---|---|
| Distributed Ledger<br>Immutable Records<br>Traceability<br>Smart Contracts<br>Data from IoT sensors<br>Peer to Peer Trading | Public<br>Private<br>Consensus | Proof-of-Work<br>Proof-of-Stake | Permissioned<br>Permissionless |

*Table 1. Factors that make up a Blockchain*

# 3. Methodology

## 3.1 Research Strategy

The study takes its background in how the concept of trust, transparency and traceability is changing in supply chain management as product become more complex, as well as how that also requires the introduction of new technology like blockchain in the more complex supply chains needed to produce these products to maintain the goal of supply chain management to maximize added value while minimizing costs while and at the same time cater to the increasing demand from customers and other stakeholders on increased transparency and traceability of the goods they purchase. Since most research is focused on technology and finance, and Bitcoin and research on other uses of blockchain is limited, more research is required. There are many issues in supply chain management where blockchain could be a solution, and many examples of experiments by companies, but few proven use cases. The study aims to provide a deeper understanding of what implications the current and future uses of blockchain technology in supply chain tracing might have for further research in the field of blockchain technology by answering the research questions of what factors makes blockchain a suitable innovation for supply chain tracing, what other technologies achieve results similar to the use of blockchain for supply chain tracing, and what implications the use of blockchain has for the environmental impact of supply chains.

This study is exploratory research that aims to explore the nature of the topic of blockchain in supply chains to provide a deeper understanding, and more specifically to provide insights within the chosen context of supply chain tracing. Exploratory research often uses for example qualitative interviews to build upon a review of existing literature on the topic to explore the topic further (Bryman & Bell, 2015). A qualitative research strategy has been chosen for this study to allow for more depth, discussions, and implications in the collected empirical material. It also allows for a more detailed analysis. This is better suited than a quantitative study when there is uncertainty and lack of knowledge surrounding the subject of the study (Bryman & Bell, 2015) as is the case of blockchain in supply chain tracing. To provide an understanding of the topic it was deemed important by the author to analyze the knowledge and perception of professionals at several different supply chain tracing companies which will be achieved by primary data collection in the form of qualitative semi-structured interviews. Semi-structured interviews allow room for further exploration of the topic, in line with exploratory research (Bryman & Bell, 2015). Along with this, inductive reasoning is used to analyze not only the

descriptions but also the perceptions given by the people being interviewed, with the aim of building on theory and logic interference with the world, which is also in line with exploratory research (Eriksson & Kovalainen, 2015; Bryman & Bell, 2015). This is well suited to the topic of blockchain since it is a relatively new field of research.

## 3.2 Research Design

This study follows the design of a multiple case study, as opposed to a single case study, as the research question benefits from the views of several companies to explore solutions, rather than diving deep into the solution of a specific company. This choice is further strengthened by the increased quality of searching information from several sources (Bryman & Bell, 2015). The design of this study is exploratory in the way that the review of existing literature is used as a base on which the new data created through interviews is used to expand the studied field by analyzing the results with the goal of answering the research question. Furthermore, the exploratory nature of the result will also serve to provide suggestions on further research on the topic. Exploratory research will not have the goal of providing definitive results (Bryman & Bell, 2015). The choice of a multiple case study is to get more different views from several companies which increases the quality of the study by collecting data from different sources.

## 3.3 Data Collection

Primary data is collected through semi-structured interviews with people working with blockchain solutions at Europe-based supply chain tracing companies using blockchain technology. Semi-structured interviews allow the interviewer to explore the topic further by asking follow-up questions while still maintaining the same fundamental structure of all interviews (Bryman & Bell, 2015). Secondary data in this study consists of other documents, reports, webpages, and industry related blogs, and acts as a way to access more data without spending the time of generating new primary data (Bryman & Bell, 2015) and is also used to narrow down and formulate a research question. The literature review was conducted using a snowball sampling method on the material found through the keywords from online databases like EBSCO, Science Direct and Scopus, rather than a systematic literature review, as ensuring high relevance in the referenced material was determined to be more important than the broad view of the chosen topic associated with a systematic literature review (Bryman & Bell, 2015). The sources of the literature review is peer-reviewed articles and research published in academic journals. The main method of attaining these articles was by using the Supersök

function at the University of Gothenburg University library database. The reason to start with a snowball sampling literature review is to start by looking at what is already known in the field of research today, and what is not known. This helps with both formulating a research question, and also forming a base of theory to which the empirical findings from the interviews can be compared and explained. This allows for a more detailed analysis, and the inductive reasoning helps to analyze both descriptions and perceptions from the interviews (Eriksson & Kovalainen, 2015).

In terms of data collection there are two approaches within qualitative research, the first being the planned-systematic approach to data collection and the second being the emergent-spontaneous approach. In the case of the planned-systematic approach the researcher starts by setting up as clear of an idea of the subject of the study as possible before planning the process of collecting the data, then the researcher conducts the interviews and the results are studied after the data collection is finished, analyzing all data from the interview transcripts at the end of the study. This means that the researcher will only know if the findings are interesting with regards to the study after both the data collection and analysis is completed. In the case of the emergent-spontaneous approach the researcher start the field work or data collection before setting up an idea of the subject of the study, the researcher waits until something interesting or revealing happens during the field work, described as rather than the researcher finding the empirical material, the empirical material finds the researcher, which might appear unscientific and opportunistic, but the emergent-spontaneous approach has a greater potential in finding interesting material, as compared to the planned-systematic approach, depending on how well planned it is. The emergent-spontaneous approach requires the researcher to be more opportunistic and responsive when a situation arises while doing field work or data collection, it is also a more risky approach as it may require a lot of time to find an interesting situation, and even risk not finding an interesting situation to study at all. If the intended audience are academics, the unscientific nature of this approach might be unfavored. (Alvesson, 2003).

As there is scarce research on blockchain used in supply chain tracing, a pre-study following the emergent-spontaneous approach is conducted as an open dialogue with one or more experts to aid in ensuring that the interview guide is updated and relevant, as well as which people within the organizations are the most relevant to interview. After the pre-study, the study switches to a more planned-systematic approach for the interviews. The main method of finding relevant companies was by using the search engine Google which yielded 10 companies in Europe working with a blockchain-based solution for supply chain tracing which were the following companies: Circulor, Everledger, Scantrust, Xylene, CircularTree, Minespider, TrusTrace, Haelixa, Limechain and Digital Catapult. The main method of contact was Linkedin to find people with relevant roles at these companies. Well over 100 people were successfully contacted individually by the researcher using telephone if a number was available, email if an address was available, or the Linkedin message function if no other contact information was available. This resulted in 8 people accepting an interview. Out of those 8, the researcher was able to schedule and execute interviews with 6 of them during the time of the data collection. Below is Table 2 which is a table of the interviews, what company and position, the date and duration, and the setting and language of the interview.

| **Company** | **Position** | **Date** | **Duration** | **Setting** | **Language** |
|---|---|---|---|---|---|
| CircularTree | CEO | 13/5 | 26 min | Digital | Swedish |
| Minespider | CEO | 14/5 | 40 min | Digital | Swedish |
| Everledger | Frontend Engineer | 17/5 | 43 min | Digital | English |
| Everledger | Backend Engineer | 18/5 | 31 min | Digital | English |
| TrusTrace | Business Development Manager | 24/5 | 40 min | Digital | Swedish |
| Scantrust | CTO | 24/5 | 30 min | Digital | English |

*Table 2. Table of interviews, including company name, interviewee position, date, duration, setting and language.*

A general problem with qualitative studies based on interviews is finding the right people to interview and to be able to actually schedule and conduct the interviews. Since the study relies on generating new data dependent on the perception of these people, it is crucial to plan the interviews well to make sure this succeeds. This is especially true in the case of this study since it is difficult to find people with enough expertise to be willing to be interviewed about blockchain in supply chain tracing, this was mitigated by talking to the interviewees before the interview to discuss the topics to make sure the interviewees were comfortable doing the interview. Another problem with qualitative is that the collected primary data is based on the perceptions of the people that was interviewed, which are subjective and will depend on which specific individuals are being interviewed and may also be affected by which questions the interviewer asks and how the questions are formulated, as well as which follow-up questions that are asked in these semi-structured interviews. To mitigate this the questions were each connected to the theoretical framework and revised between interviews to make sure the questions were clear and understandable. Furthermore, the analysis of qualitative data will always be subjective and dependent on the perception and judgement of the researcher, an effort to mitigate this has been made by always connecting the analysis to the theoretical framework. Still, all of these points make the validity, reliability and replicability of a study of this nature low, which can be seen as a problem in terms of how scientifically correct the conclusions of the study should be considered. This should however not be the focus of this qualitative study, as it aims to build theory rather to test existing theory.

## 3.4 Data Analysis

The results of this study was analyzed using a thematic analysis, as it is an appropriate way to extract themes when working with qualitative data (Bryman & Bell, 2015). This is done by coding the interview answers into codes that are in line with what has been found in the literature review (Bryman & Bell, 2015). First the interviews are transcribed, then each of the answers and statements in each interview is condensed down into coded in the form of short phrases that aim to convey the meaning of each statement in order to drive the key points of each interview. The aim of this is also to codify the interviews without losing the perceptions and insights provided by each respondent. The interviews were recorded through Zoom meetings, then the audio was played back and transcribed automatically using the dictate function of Microsoft Word. The resulting transcription was not accurate, likely due to many technical terms, but it still saved the researcher time, even if many manual corrections of the transcripts were needed. The interviews were then coded and the codes were summarized in a Microsoft Excel file. All of the codes were then categorized into broader themes that summarize the key points of the study. These themes were then compared to the findings of the literature review to be able to draw conclusions regarding the collected data in order to answer the research question.

The relationships between strategy, design, data collection and analysis are that all parts need to function coherently together to allow the study to answer the research question (Bryman & Bell, 2015). Since the purpose is to explore the uses of blockchain technology in supply chain management and the field of blockchain is a fairly new field of research, is fits to apply the combination of a snowball sampling literature review, qualitative semi-structured interviews, explorative research and inductive reasoning (Eriksson & Kovalainen, 2015). The reason for choosing exploratory research is to provide a deeper understanding and new insights on the topic of blockchain. The choice of qualitative, semi-structured interviews was made to allow this exploratory research to take place by allowing the interviewer to ask follow-up questions while still following a structure (Bryman & Bell, 2015).

# 4. Empirical Findings

## 4.1 Blockchain technology in Supply chain management

To determine the reasoning behind using blockchain technology and why it is a suitable technology for use in the context of supply chain management, the respondents were asked to explain the reasons why blockchain is a suitable technology for use in supply chain management. The results show that the interviewed companies all use blockchain for various services related to supply chain tracing. CircularTree is using blockchain in tracking product carbon footprint, Minespider creates product passports for tracking products using blockchain, Everledger is using blockchain to aid in proving authenticity of products, TrusTrace uses blockchain to trace environmental and social impact of textile supply chains. Scantrust differs as it was found to not be based around blockchain, rather the focus is on IoT, QR codes and RFID for anti-counterfeit and supply chain tracing applications, but they have used blockchain in some projects. The respondents of both supply chain tracing companies CircularTree and Minespider, both of whom were in the position of founder and CEO, stated that one of the main reasons for using blockchain technology is that the technology increases trust. Both respondents define the increased trust as that blockchain allows a technologically trusted way to verify data. Despite minor differences in chosen words all respondents agree on the point of using blockchain as a trusted way to verify data. Nathan Williams, Founder and CEO of Minespider, explains trust in the following way:

> "A lot of the reason that you use a blockchain is to agenda trust, right? So, part of trust is having the ability to verify, right? So, like you know, the old mantra, "don't trust, verify", or maybe rather "trust, also verify", either way the idea is: How can you reduce the cost of trust? The main benefit for someone that doesn't know blockchain, so for supply chain actors, is that they're able to digitize their documents and send them and have a better line of communication with their customers, and they trust that if there was a problem with the system itself, above data corruption, that it would be possible to verify the fact that the blockchain exists." (Nathan Williams)

Williams explains that he views Blockchain as lowering the cost of trust, rather than increasing trust or replacing the need for trust. He also explains that blockchain has already proven that users can trust its ability to verify data, and this means that the user do not need to know how the technology works, just know that it works. Gunther Walden, Co-Founder and CEO of CircularTree gives similar, but not identical, reasons for using blockchain technology:

> "The reason for using blockchain in particular is that it adds an additional layer of trust, the data is immutable and transparent, and you are able to easily verify when and where the data is coming from." (Gunther Walden)

Differing from Williams, Walden views Blockchain as adding an additional layer of trust. An additional layer of trust in the form of the ability to verify the data, since the blockchain is transparent and that the data is also immutable and cannot be altered. Walden gives the example that CircularTree calculates product carbon footprint throughout the supply chain, which means that the calculations of each step in the supply chain build upon the calculations provided by the previous step upstream in the supply chain. In this situation the transparency and immutability of blockchain offers the users confidence that the data can be verified, it also allows them to prove to their customers that their calculations are correct in relation to the data they are based on. It is possible to verify where the data comes from and even when the data was recorded, which makes it easier to divide the accountability among each of the actors throughout the supply chain since when data is traced back, each company can prove what input and output data they have. This means that if a calculated product carbon footprint is too far from a predicted estimate and an error is suspected it is easy to trace back throughout the supply chain to find where the calculations deviate from expected values and check if the input data is correct and find where the problem lies. This forces each actor in the supply chain to be accountable for their own calculations and output data, but allows them to not be responsible for the other parts of the supply chain, since all data can be verified.

## 4.2 Trust in Relation to Blockchain in Supply Chains

Since one of the reasons for the creation of blockchain in the case of Bitcoin was to eliminate the need for financial intermediaries, which have the primary function of instilling trust and act as guarantees for transactions, it was of interest to examine how this trust aspect relates to the different companies interviewed in this study. Walden gives the following answer regarding CircularTree:

> "In our case, each actor uses the input data they receive from upstream actors added to their own calculations of product carbon footprint, and the data can be traced back, so each actor is responsible only for their own data. The trust aspect can be that a stakeholder or downstream actor asks another actor to prove to me that the data you have is correct, and blockchain allows them to verify that. Blockchain is fully transparent, which builds confidence and trust in that the data is correct." (Gunther Walden)

The transparency, immutability, and ability to verify is what makes people trust blockchain as a technology, which in turn makes people trust platforms that are using blockchain technology. When talking about trust in relation to blockchain, Williams of Minespider says he prefers the idea of blockchain reducing the cost of trust, and some blockchain applications are more vulnerable than others. He says that it is a tradeoff where the more power you have, the less you have to trust the third party, but less recourse you have and the more you have to trust yourself, trust is rather moved. He exemplified that Bitcoin can be used without banks, but it's up to the buyer and sender to make sure money goes to the right address. He goes on to talk about trust in supply chains:

> “When you're dealing with something like supply chain and tracking it's a different level of trust, right? Like, what are you trying to trust? You're trying to show you how trustworthy in one sense, by providing more data, you're trying to reduce the cost of trust like. Previously, you might have requested information from all of your suppliers, right? And big companies do this all the time, so they'll say. OK, we wanna make sure there's no human rights abuses. and send a questionnaire to thousands of suppliers to please tell us all of the measures you've taken, and then they have to send it to their suppliers and suddenly you've got thousands of data points to sift through. Most of them won't even get back to you […] it becomes an absolute nightmare. There's no single standard. So the thought process of this is can you connect all companies so that you can cross reference, not just the responses, but who gives a responses and sift through this in a better way. Can you calculate risk scores, attach ESG metrics to a product and to start to inform your credit rating for the company to take some shortcuts in who you would trust and who you wouldn't, and part of the idea with blockchain honestly is building something like the Internet, something overarching multiple people and companies can pull from. Multiple companies can pull from. So you don't have to repeat this same process 10,000 times.” (Nathan Williams)

Williams continues by saying we are far from achieving the Internet-like blockchain since different companies have different data, but that it is a vision that would open the market with each company having a data profile.

## 4.3 Integrity and handling of sensitive data

Since blockchain is a distributed ledger described as allowing full transparency and immutability, it was of interest to ask the responding companies how sensitive information is handled, as there may be pieces of information that is sensitive to a company that is participating in a blockchain, that the company does not will to be publicly visible and as the immutability aspect prevents the information to be taken down once it is on a blockchain. Both CircularTree and Minespider hash the information before it is added to the blockchain. A hash function is used to map the data into a fixed size value. This method of storing data means that the data is only viewed as a value, but it can be verified by putting the original data through the hash function again. Walden explains how it is done at CirculorTree in the following way:

> "We do not add the actual data to the blockchain, since the data can be sensitive. We hash the data before it is added to the blockchain. The hashed data can be used to verify that the source data is correct, but the source data cannot be viewed from simply having the hash that is on the blockchain." (Gunther Walden)

This way of hashing the data means that no sensitive data can be viewed publicly on the blockchain and removes the problem of transparency and immutability of sensitive data on a blockchain. This method is deemed very secure, Walden exemplifies by a pilot project that CircularTree is currently running in the healthcare industry, where Walden argues may be the industry with the most sensitive data of all industries, but even here the trust in the technology is high enough that blockchain technology can be used even in the healthcare industry. Minespider is also hashing the data before it goes on the blockchain, the original data is stored in a so-called product passport, which much like the name implies is a passport that a product carries throughout the supply chain. The data from the product passport is then hashed before it goes on the blockchain. Williams described the process the Minespider is using in the following way:

> "The purpose of the blockchain is just to store hashes of the product passports. Product passports and cells are stored in a public database and not stored in the blockchain itself. What we do is we encrypt the private and the transparency layers of the product. Then we encrypt those with a public key of the owner of that data which can be accessed by the sender and the receiver [of the product the passport refers to]. So its center can be decrypted and read those private transparent layers. Everyone can read the public layer and then the hashes of those layers are stored in the blockchain so that everyone can verify that the data is unchanged and unchangeable but only the owners of the data can read it. So, on the blockchain is only the information that is already hashed." (Nathan Williams)

What this means is that anyone in the network can verify that the data is correct and unchanged, but it is not possible to read the actual data. The actual data can however be decrypted by a key that is held by the owners of the data. This mechanic allows the data to be verified by everyone, but only readable by the owners of the key that decrypts the data. At Everledger the same is true, the information is only viewable through a private key. Plimmer states that blockchains in general are open source but that it is not a blockchain specific thing, there is Open Source Software, and there is Private Software, Everledger has chosen the private path in favour of the open source path. The blockchain of Everledger is transparent if you have the private key.

> "Blockchain data will always get hashed regardless of whether it's a private blockchain or public one. They key point is that, our blockchain data is private to our clients however if our clients wants to share their blockchain data with other people, we can give them API key's to access the private blockchain." (Jim Plimmer)

## 4.4 Alternative Technologies to Blockchain for use in Supply Chain Tracing

To build further understanding for the motivations behind using blockchain as a technology for supply chain tracing, the respondents were asked what alternative technologies there are to blockchain that can be used in the same contexts and provide the same results. Neither Williams nor Walden knew of any technologies that offer the same level of trust in its immutability and ability to verify data. Williams starts by jokingly saying that you achieve the same results in the context of supply chain tracing by simply using pencil and paper, passing the notes, but continues by saying that the reason that blockchain is used is to agenda trust through the ability to verify digitized documents and to easily communicate the information to their customers. He also suggests that theoretically a non-profit organization that was transnational could hold a central encrypted database of the entire world supply chains, but that once again brings up the question of why we should trust them. Walden gives the following answer:

> "As far as I'm aware there are no alternative technologies that offer the same level of immutability as blockchain does. If we look at blockchain as simply a distributed ledger then yes, there are alternative technologies for creating distributed ledgers. But in terms of immutability, no, there are no alternatives that I know of." (Gunther Walden)

Walden means that viewing blockchain technology as simply a distributed ledger, which is what blockchain is and often described as, misses the strengths that blockchain technology brings and that makes it unique. Which refers to the level of immutability and ability to verify data that blockchain offers. He says that today many supply chains use excel documents that they send back and forth which accomplishes the same functions but without the immutability aspect and without the ability to verify. He gives the example that a downstream actor may point out a mine or production facility that has not been accounted for and send the document back up the chain for correction and sometimes the issue is resolved, other times the responsible actor may have just removed the mine or production facility altogether and there is no way of knowing if the numbers are correct or have been tampered with. Williams' take on the answer is to flip the question around in the following way:

> “Imagine that we didn't have a blockchain. We just had a centralized database, right? So, we could set up a centralized encrypted database, but without the ability to verify the data integrity. And if I have the ability to give or check all of the passwords and things like that, there's an open question as to: How secure is the data? Are there going to be data leaks? Is there going to be data mining? Now, the most important thing with something like blockchain is to be able to reduce the cost of trusting a system like this, but then the second thing that comes along when you have a sort of this immutable system is to be able to sell it internally.” (Nathan Williams)

In other words, blockchain has strengths in its ability to verify data and its immutability, which is much in line with what Walden stated as well. Then the second point that Williams mentioned, he also went on to elaborate further on by stating that blockchain has an ability to be sold internally, employees using blockchain sees that it keeps data secure and also increases transparency and allows tracking which helps users sell the technology to managers that are not users of the technology. The proof that it works over and over helps to sell blockchain technology to investors and governments as well. Williams urges not to overlook the marketing aspect of blockchain, that people use blockchain because it has a reputation for being able to keep data secure while offering increased transparency, and that when people know that blockchain can do these things, it helps overcome internal barriers.

## 4.5 Sustainability, Energy Consumption and Consensus Mechanisms

With the growing awareness from stakeholders concerning the environmental impact of producing companies it was of interest for the study to look at what benefits using blockchain technology in supply chain management has for measuring and lowering the environmental impact to move towards a more sustainable way of producing. To ensure open ended answers the respondents were asked about the importance of these various uses of blockchain and they are contributing to society which yielded many different answers. The respondents were also asked about what blockchain they are using and what consensus mechanism, since that will drive the energy consumption of the actual blockchain which becomes an interesting topic when the goal for these companies’ use of blockchain is to lower environmental impact. To return to the first question about the importance and the contribution to society, Hannes

Lindfred at TrusTrace says tracing companies offer big contributions when consumer and product companies set goals to be more sustainable as a result of regulations and pressure from stakeholders. When these companies are required to report both their social and environmental impact, they need to know who they are sourcing materials and components from and be able to measure the impact to be able to make decisions on how to improve sustainability the most, and not focus on the wrong areas. Lindfred gives the following example:

> "According to what I have read, many consumer and product companies switch to led lights in the office, and switch to electric cars, but 90-95% of their environmental impact comes from their supply chain, mainly from materials and components. Then you're in trouble if you set a goal to lower your impact but you don't know where 90% of the impact comes from. This is why tracing companies are important, to help companies get the data that allows them to make these important decisions." (Hannes Lindfred)

Walden at CircularTree talked about the importance of actually calculating the product carbon footprint when the goal is to lower it, and not just make estimations and he gave the following answer with regards to CircularTree:

> "We are unique in the way that we are using calculated product carbon footprint tracking, it is not just estimates like other companies may do, that is the difference, working toward more sustainable production. We have developed a global standard for comparable tracking that is cross-industry. We have developed an open standard for communication to provide users with an ecosystem for interoperability." (Gunther Walden)

Here Walden also talks about the importance of open, global standards for tracking product carbon footprint that can be compared over different industries.

Regarding energy usage, all of the respondents report using other mechanisms of consensus than the proof-of-work that is used for Bitcoin and is the reason for the high energy usage of Bitcoin. Williams explains that Minespider uses a consensus mechanism called proof-of-authority which he says is a standard way for the type of public permissioned blockchain they are using where everyone who currently runs a node on the network, meaning the members of the blockchain, has a vote on who could join and all of the nodes take turns confirming blocks in order to reduce energy costs. This means that the computers on the network are helping each other to confirm blocks, instead of competing to create blocks, like in the case of Bitcoin. He also says that the platform is built to work with any blockchain, but they use the proof-of-authority for the low energy cost. He says that it would not make sense to use a blockchain with high energy usage with the goal to track and lower carbon emissions. The respondents from Everledger, TrusTrace and Scantrust all did use or have used Hyperledger blockchains, which also uses a form of proof-of-authority consensus mechanism, and they are all also using permissioned blockchain, which means new nodes needs to be voted in to join which protects the supply chain actors from outsiders.

### 4.6 Smart Contracts and the Internet of Things

In the literature it was found that blockchain could be used to aid in different forms of automatization, like constructing smart contracts in peer-to-peer trading that hold the payment until certain conditions are met, like that the good has been delivered, and then automatically transfer the payment to the seller (Capgemini, 2017). It was also found in the literature that blockchain could be used in combination with the IoT in a supply chain, where products and machines with sensors and internet connection could upload information to the blockchain automatically about how and when goods have been shipped (Christidis & Devetsikiotis, 2016). Through the interviews it was however found that all 5 of the interviewed companies are using platforms for human input of data rather than automatic input made using data from sensors of IoT products. All 5 of the interviewed companies are using blockchain as a platform for supply chain tracing through the actors of the supply chains. The contracts between buyer and seller are handled outside of this platform through regular contracts, smart contracts are not utilized as a part of the blockchain solution.

# 5. Analysis

## 5.1 Blockchain technology in Supply chain management

The immutability characteristic of blockchain, and its ability to let users verify data which in turn creates transparency, which creates trust in the system, appears to unanimously among all respondents be the central reasons behind using blockchain technology for supply chain tracing and why it is a suitable technology for use in this context. The trust aspect is by many respondents defined as the increased trust as that blockchain allows a technologically trusted way to verify data. Many respondents also seem to agree that even though there are many different ways to configure a blockchain application technically, the most important thing for users is that the technology is proven to work, if that is the case, the users trust the technology and care less about how the technology works. These aspects were all mentioned in the literature review as well, however the definition of trust appears to differ. In the literature trust is mentioned in many contexts, but one that differs from the results of the interviews, is that blockchain would replace the trust-based model for trading, where a financial intermediary builds the trust between parties, in favor for peer-to-peer trading using blockchain. The tracing companies are using blockchain to ensure verifiable immutable data, not for peer-to-peer trading.

## 5.2 Trust in Relation to Blockchain in Supply Chains

Eliminating the need for a third party like a financial intermediary to instill trust was one of the reasons for the creation of blockchain in the case of cryptocurrency like Bitcoin (Nakamoto, 2009), and that the trust in the blockchain technology should allow peer-to-peer trading and interestingly enough it could be argued that these supply chain tracing companies that are offering a blockchain based tracing service in reality is actually a new form of third party that the actors in the supply chain need to trust, making these tracing companies a form of intermediary. The interviewees however, defined trust in a different way, they defined trust as trusting the technology's immutability and ability to verify, rather than as a replacement for financial intermediaries. Williams talked about Blockchain as reducing the cost of trust, and that it is a tradeoff where more power requires less trust in a third party, but requires greater responsibility from the user, and that trust is moved, this supposed tradeoff was not found to be mentioned in the literature review.

## 5.3 Integrity and handling of sensitive data

While integrity and handling of sensitive data was mentioned as a problem in literature due to the fact that it is very difficult to remove information from the blockchain since the ledgers are permanent and immutable, and that it is difficult to handle these problems on a public blockchain since the technology prohibits any form of model of governance to be applied, it does not appear to be of any concern for the companies offering supply chain tracing. Several of the interviewed companies did not handle any sensitive data in the first place, and the interviewed companies that did handle sensitive data, hashed the data before it was added to the blockchain, so the actual sensitive data is never on the blockchain.

## 5.4 Alternative Technologies to Blockchain for use in Supply Chain Tracing

There were no alternative new technologies to blockchain found in literature and none of the interviewees knew of any alternative new technologies to blockchain that can be used in the same contexts and provide the same results. It seems that the level of immutability and ability to verify data was especially unique to blockchain. The example that a non-profit organization theoretically could be used to store the data instead, but with the problem that all companies would need to trust them with their data, and the data would not be immutable in the same way as on a blockchain. If the term alternative technologies is viewed more broadly as way of storing and sharing information, the current alternative in using Excel files to store supply chain data that is commonly used today has the same problem where it lacks immutability and instead requires all actors to trust each other, and the same is true for other forms of distributed ledgers. Looking at printed paper documents, they could be seen as somewhat immutable since it would be visible if alterations were made by a pen, but there is no way to verify that the information that was printed is correct or if it has been altered on a computer before printing.

## 5.5 Sustainability, Energy Consumption and Consensus Mechanisms

In the literature there were problems highlighted with the cryptographic verification model proof-of-work that is used today. Proof-of-work is inefficient, validation is slow and costly and very energy consuming and that all copies of the blockchain also require a lot of storage space (Simchi-Levi et al. 2021). It appears that these problems have been taken care of in the context of the blockchains used by the interviewed supply chain tracing companies by the use of the consensus mechanism called proof-of-authority where everyone who currently runs a node on the network takes turns confirming blocks in order to reduce energy costs. This instead of the proof-of-work usually used for crypto-currencies like Bitcoin (Simchi-Levi et al. 2021), which means the supply chain tracing companies solved the problem of energy consumption for blockchain in supply chain tracing. Regarding the issue of storage space, this is also a problem of crypto-currency blockchains like Bitcoin, since it is permissionless and there are so many nodes on the network, but since the supply chain tracing companies use permissioned blockchain, the only nodes on the network are usually the supply chain actors, which means the blockchain is stored on much fewer computers, which solves the issue of unnecessary storage space.

## 5.6 Smart Contracts and the Internet of Things

None of the interviewed companies were found to use smart contracts as a function on the blockchain platforms they use, neither were any of the companies found to be utilizing any connection to retrieve data from sensors on IoT products. The reason for this might be that the supply chain tracing platforms used by the interviewed companies are built around human input of data rather than automatic input made using data from sensors of IoT products. There was also no use of blockchain for peer-to-peer trading in the blockchain solutions provided by these supply chain tracing companies. The reason for this might be that the use of blockchain in supply chain tracing is very different from the blockchain generation 1.0 with cryptocurrency, as well as blockchain 2.0 digital finance and blockchain 3.0 digital society described by Zhao et al. (2017) as these are generations of blockchain for use in the field of finance, whereas the use of blockchain in supply chain tracing does not use the peer-to-peer trading, smart contracts and internet of things, but rather goes back to the roots of blockchain technology as a distributed ledger for its immutability and ability to verify information. Smart contracts may not be reasonable to integrate into these supply chain tracing solutions, as they are not focused on

peer-to-peer trading and that contracts between buyer and seller are handled outside of these supply chain tracing platforms.

# 6. Conclusions

## 6.1 The factors that makes blockchain a suitable innovation for supply chain tracing

The factors that make blockchain a suitable innovation for supply chain tracing seem to all be within the functions factor in the framework presented in the theory section, and they all appear to be as a result of one another. At the core is the immutability that means that the data that is recorded on the blockchain cannot be tampered with, this seems to be a characteristic that is unique to blockchain, at least in terms of the high level of security that prevents tampering. The immutability in turn allows users to verify data. Verifiable distributed data creates transparency. All of these factors together create a system that is proven to work, and that proof appears to create trust. Once trust has been built it seems that the actual technical configuration of the blockchain is of less importance to the users, if the system is proven to work, the users do not need to understand how it works. Overall, these factors are in line with what was described in literature, apart from blockchain as a replacement for trading with intermediaries in favor for peer-to-peer, which is not how blockchain is used by supply chain tracing companies.

## 6.2 The lack of alternative technologies to blockchain for supply chain tracing

It would have been of great interest to find alternative technologies in terms of other new innovations that offers the same level of immutability, ability to verify, transparency and trust that blockchain offers, however the conclusion from this study is that no alternative technology that offers all factors mentioned above was found through the literature review, nor were any alternative technologies known by any of the interviewees in terms of these factors. If the term alternative technologies is viewed more broadly as a way of storing and sharing information in supply chain tracing, the alternatives would be paper based documents, or digital documents in the form of excel files. While some interviewees mentioned that blockchain at its core is a distributed ledger, and that other distributed ledgers exist that may offer transparency, but that without the blockchain, the immutability aspect is lost, and with that the ability to verify is lost, which reduces the trust in the system. Because of this, the conclusion of this study on this point is that no alternative technology is known that offers the same level of immutability as blockchain does.

## 6.3 Implications for Practitioners

The findings of this study have some implications for practitioners. To begin with, contrary to what was found in current literature, handling sensitive data on a blockchain does not have to be an issue in practice as there are solutions like hashing the data before it goes on the blockchain which means the actual data is not on the blockchain, in case it would need to be removed due to legal actions or privacy regulation. Also, several of the interviewed companies did not handle any sensitive data in the first place. The next implication is about the concerns raised in literature about the cryptographic verification model used today being inefficient, slow on validation, costly and having high energy consumption, requires a lot of storage space. This all refers to the proof-of-work consensus mechanism, but that is not what is used in supply chain tracing. Instead, proof-of-authority is used, which solves all of these problems, and maybe most important of all, it requires far less energy.

## 6.4 Future Research

This study has served as exploratory research to find how and why blockchain is used in supply chain tracing what factors makes it suitable. The study implies that blockchain in supply chain tracing has less negative impact on the environment than suggested in current literature, the study also implied that greater positive impact on the environment than suggested in current literature. The study also serves to show that some concerns about blockchain stated in literature, like the problem of sensitive data, already has solutions like hashing the data before adding it to the blockchain. The study is qualitative however and does not have results in numbers that can prove any of the above-mentioned points. Further quantitative studies would be needed to find out if the positive environmental impact of using blockchain is greater than the negative, to yield a positive net effect on the environmental impact of supply chains which would help as proof to determine if blockchain would be considered a sustainable solution for supply chain tracing.

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# Appendix

**Interview Guide**

Primary questions

1. Please describe your (insert company name) offering?
2. Explain the reasons for using blockchain as a technology?
3. What does blockchain do, that alternatives do not?
4. What alternatives are there?
5. Replacing the need for trust was one reason for the creation of blockchain, in what ways does that relate to your business?
6. Are you handling sensitive data, how is it handled?
7. What blockchain are you using?
8. Explain your consensus mechanism?
9. How is the authority divided?

Secondary questions

1. Please describe your product.
2. What are you observing happening in supply chain management today?
3. How has supply chain management changed in recent years?
4. In what ways has regulation changed and how does that impact supply chain management?
5. What challenges are typically associated with supply chain management today?
6. What innovations do you see happening in supply chain management today?
7. How close are relations typically between buyers and supplier in a supply chain? Does it vary by segment? (Industry, geography, company size)
8. To which degree do you view supply chains as a chain, versus a network? Does it vary by segment? (Industry, geography, company size)
9. What is the view on sharing systems within the supply chain? Does it vary by segment? (Industry, geography, company size)
10. What is the need for information in a supply chain? What type of information? Does it vary by segment? (Industry, geography, company size)
11. What problems in supply chain management can be solved using blockchain technology?
12. What results or effects can be seen from implementation of blockchain in supply chains?
13. What type of blockchain is used and how is the authority divided?
14. What is the level of immutability? Can information be altered?
15. Are cyber-attacks considered a threat? Are there systems in place to prevent it?
16. What is the transaction speed like for new blocks? How are situations with high traffic of new information on the blockchain handled?
17. How flexible is your blockchain in terms of changing rules and functionality?
18. Replacing the need for trust was one reason for the creation of blockchain, in what ways does that relate to your business?
19. To what degree does your customers use your platform as a proof to replace the need for trust?

20. What is the transparency like on the platform you provide?

21. Who has access to what information and what restrictions are in place?

22. To what degree does your customers use your platform to increase transparency of the blockchain?

23. What level of traceability through the supply chain does the blockchain allow for?

24. To what degree does your customers use your platform to increase the traceability throughout the blockchain?