Supply Chain Automation with Smart Contracts – Assessing Potentials of Blockchain Technology in the Logistics Sector

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As economies are getting more and more interconnected, the importance of the global logistics sector grew accordingly. However, both structural challenges and current events lead to recent supply chain disruptions, exposing the vulnerabilities of the sector. Simultaneously, blockchain has emerged as a key innovative technology with use cases going far beyond the exchange of virtual currencies. This paper aims to analyze how the technology is transforming global logistics and its challenges. Therefore, six use cases, are presented to give an overview of the technological possibilities of blockchain and smart contracts. The analysis combines theoretical approaches from scientific journals and combines them with findings from real-world implementations. The paper finds that the technology can change supply chain design fundamentally, with processes and decisions being automated and power within supply chain structures changing. However, implementations also face technological, environmental, and organizational challenges that need to be solved for wide-spread adoption.

1. Introduction

This paper is going to analyze the possible applications of DLT in the supply chain context. The main question to be answered is whether and how the technology can be used to overcome existing problems in Supply Chain Management (SCM) and how to create additional value to supply chain stakeholders. Therefore, 4 key questions are to be answered:

1. How do distributed ledgers work from a technical perspective? What are the currently available options available for real-world implementation?
2. What use cases using DLT have already been theoretically developed? Have they seen successful real-world implementation?
3. What are major problems related to the implementation? Are they a thread for the future success of DLT in Supply Chain Management?
4. Taking everything into consideration; how impactful is the technology going to be for the future of supply chains?

To answer that question, first, a short analysis of both the global logistics sector and the status quo of blockchain technology is being given. Afterwards, a detailed analysis of how Distributed Ledger Technologies (DLT) can bring innovation to the logistics sector is being given. Therefore, a deep dive into six use cases is conducted, including both economic and technological perspectives. Finally, these findings are being discussed regarding challenges and overall future implications for the industry.

2. Theoretical Foundations

This chapter is going to give an overview of important basics and notations for this paper. First, the current state of the logistics sector is being outlined. Afterwards, important foundations of DLT are being introduced.

2.1. Status Quo of the Global Logistics Sector

With the trend of globalization in the last decades and the establishment of more and more interconnected supply chains, logistics have emerged to become a central part of the global economy. According to the World Bank, the global GDP peaked in 2019 at $84.6 trillion [1]. 11% of this GDP, $9.3 trillion, are thereby trade-related costs [2]. This is up from 2010, were trade-related costs made up 10.53% of the global GDP at that time. the global logistics sector can be divided into several subcategories. It is notable that over 55% of the market can be contributed to the two largest categories, with “Road Freight Transport” being the largest with 32.43%, followed up by “Warehouse and Distribution” with 26.67%. After that, a large gap occurs, and the following categories “Domestic Parcel Delivery” and “Contract Logistics” can consequently only contribute to less than 5% of the entire market.

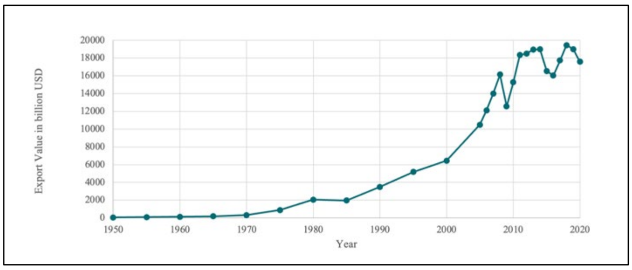

Figure 1: Trade Export Value in billion US dollars [3]

However, while enabling modern globalization, the logistics sector also faces challenges. Looking at the data of Global Trade Export Value in figure 1, we can see that from 1950 to 2008, the growth of the global trade export value was only accelerating. However, since 2008, we can analyze both a general slowdown in year-to-year growth as well as 3 major pushbacks in the years 2008, 2014 and 2019.

This can be traced back to two structural problems of the sector as well as current geopolitical events. First, the high uncertainty among supply chains leads to an increasing amount of disruption. In 1996, Richard Wilding introduced the “Supply Chain Complexity Triangle”, combining all major sources of supply chain uncertainty into one framework [4]. The three dimensions thereby are “Amplification of Demand”, “Deterministic Chaos” and “Parallel Interactions”. Second, the increased use of Just-in-Time Manufacturing in the recent years furthers stresses global trade. While the “strategic implementation of the JIT approach significantly improces manufacturing performance” [5], it also leads to less resistant supply chains that do not tolerate a large amount of disruption because of low reserves and high interdependencies.

Additional to the structural challenges, current geopolitical events further strained the interconnected logistics sector. The most notable event was thereby the Covid-19 pandemic. The measurements against the spread of the virus caused a wide range of new challenges and problems to the global economy and supply chains. Even after the introduction of vaccines in 2021, local outbreaks in producing countries like China and Vietnam regularly lead to lockdowns and disruptions along the entire supply chain [6]. On 23 March 2021, one of the most used shipping routes in the world, the Suez Canal, was blocked by the container ship Ever Given. Over 400 vessels were directly affected by the event, leading to an economic damage in the billions [7].

2.2. Technological Foundations of Distributed Ledgers

To analyze use cases in chapter 3 and the overall impact on the industry in chapter 4, it is important to firstly understand the theoretical foundations of the technology. Therefore, important concepts and their technological boundaries of DLT are being introduced.

First, it is important to understand the difference between centralized, decentralized, and distributed data processing. Centralized Computing refers to a data set controlled and operated by one entity. This entity has the entire power to decide upon changes in the data set. Decentralized Computing means that data and/or computing is shared across at least two entities. These entities can however have different roles, for example one is allowed to only access the file, while another is allowed to change the data set. Distributed computing is a subset of Decentralized Computing. All data and decision power are shared across multiple servers in the system, also called nodes, with each node having the same rights [8].

Blockchain is one implementation of a distributed ledger. As its name suggests, its data is stored in a chain of blocks. The data structure of a block contains the hash of the respective block, the hash of the previous block, and finally the data itself. A hash of a block is generated by an algorithmic function transforming the blocks’ data into a shorter key. It is often referred to as a “Digital Signature” of the data. Having the hash of the previous block also integrated ensures that a change of data in the previous block could directly be detected when comparing the hashes [9]. Because of its design, blockchain has far-reaching characteristics centralized data storage cannot match. Information that is stored within a block is immutable to changes, as this would require all following blocks to also adopt the changes. Additionally, the decentralization increases safety concerning failure of single nodes. As the data is spread across multiple entities, one failure is not going to have an impact on the entire system. Finally, blockchain is transparent and its data visible to all participating nodes.

To ensure all participating entities agree to the same data set within the ledger at any given point of time, a consensus mechanism is required. At the moment of writing, two mechanisms are relevant when comparing different blockchains. The first one, Proof-of-Work (PoW), requires miners. Miners are network nodes that take part in the approval process, exchanging computational power against assets. Therefore, different nodes compete against each other. The “winner” can verify the block and add it to the chain – therefore it receives a fee [10]. The second, Proof-of-Stake (PoS), also requires nodes willing to participate in the approval process. Instead of mining, nodes are required to deposit a certain amount of assets. Whenever a new block is proposed, a lottery system chooses one of the nodes with a deposit. This node can now approve the block and receive the transactional fee. As the deposit always needs to be higher than the transactional fees, there is no incentive to manipulate the system [11].

3. Analysis of Supply Chain Use Cases Using Blockchain Technology

This chapter is going to explore the application of DLT within Supply Chain Management. Therefore, a literature review has been conducted to find relevant theoretical approaches, of which six have been found. Additionally, a look at practical implementations of these approaches has been done to evaluate real-life status of the ideas. The six uses cases have been categorized in three fields of implementation, which are going to be presented now.

3.1. Increasing Supply Chain Visibility and Data Transferring

This category includes two use cases that create value by generating and using information about the supply chain and making this visible in a trusted, non-changeable way.

3.1.1. Status Quo and Problems Today

Data sharing across the supply chain is an important part of modern SCM as different stakeholder possess important information being relevant for all entities. For example, downstream retailers have better information about the final customers and overall market trends, while upstream retailers have an information advantage regarding product quality and preliminary product availability. Therefore, a lack of data sharing leads to lost sales, double marginalization, and overall customer dissatisfaction [12].

However, and according to the article “Building a transparent Supply Chain”, published in 2020 by the Harvard Business Review, current technologies are often not sufficient for data collection. This can be illustrated by the example of a simple scenario where a retailer buys a product from a supplier with a bank providing the necessary capital. For that transaction, information flows, inventory flows and financial flows are generated. However, not all flows are being saved in all the Entity-Resource-Planning (ERP) systems. Therefore, drawing the connection between all three flows and entities is, especially in a real-world complexity, ex-post not possible [13]. Using technologies like blockchain might be a solution to this problem, creating transparency and value along the entire supply chain.

3.1.2. Use Case 1: “Increasing Supply Chain Transparency”

In many industries, this need for supply chain transparency is especially important. One of those industries is the agri-food sector, where information is not only used to create additional value but is also necessary to validate the origin and quality of the products. Today, this additional information is not only requested by the retailers, but also by the final customer, who generally demands more transparency [14].

To solve that issue, different papers suggest an implementation of blockchain technology to enhance transparency. The paper “Blockchain-based Traceability in Agri-Food Supply Chain Management: A Practical Implementation” aims to design and evaluate the impact of a communication system that is based on decentralized blockchain technology [15]. Therefore, a system called “AgriBlockIoT” is presented, that combines the use of modern sensor technology and Internet of things (IoT) devices like radio-frequency identification (RFID) systems and wireless sensors as well as a blockchain network to connect them. AgriBlockIoT can then store all relevant information of the entire food supply chain and make this visible to all stakeholders. The concrete implementation varies from industry to industry, but it is necessary to list all participating supply chain stakeholders and decide-upon which information is supposed to be added to the blockchain. Additionally, for each stakeholder, IoT devices can support the data capturing and uploading. For example, the packaging company can gear up its machinery with smart weights for automatic detection and uploading of weight information.

This leads to a completely new way of interaction between supply chain stakeholder, shifting away from linear communication flows to a multi-dimensional communication model, as shown in figure 2.

Additional to the process documentation, smart contracts can be implemented to trigger certain actions when anomalies are being detected. Overall, the implementation of the process clearly holds advantages to all participating parties. Firstly, all stakeholders have all information available at any time. Second, the manual documentation and communication effort can be reduced, as shown in figure 2.

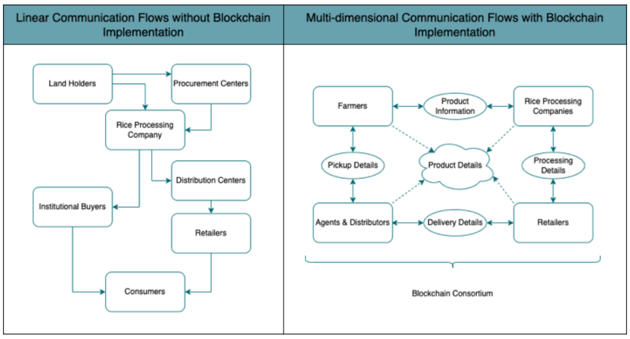

Figure 2: Communication Flows in Use Case 1 with and without Blockchain [16].

Looking at the real-life implementation of this use case, we find many companies, both established and start-ups, having tried out different approaches in that regard. One of the leading companies in that area is London-based start-up “Provenance” [17]. The company focusing on delivering transparency and value for the final customer, with their product including a proof of certificate for final customers, a digital map with all supply chain stakeholders, and integrated third-party certifications. Provence has a total funding of $6.6m, having finished the latest round worth $5.3M in March 2022 [17].

3.1.2. Use Case 2: “Enhancing Supply Chain Risk Identification”

Supply Chain Risk Management (SCRM) refers to “the implementation of strategies and plans to manage supply chain networks through constant risk assessment and reduce vulnerabilities to ensure resilience in supply chain” [18]. It is an important part of SCM. Risks can thereby be classified into two categories, endogenous risks, which includes moral risks, information delivery risks, and procurement risks, and exogenous risks, which refers to market demand risks as well as policy and legal risks [19].

An exemplary SCRM process can follow these steps in the respective order: “Identify Risks”, “Asses & Prioritize”, “Develop a Treatment Plan”, “Reduce Risk Exposure”, “Reduce Impact ex post”, “Review and Learn” [20]. It makes sense to apply the findings of use case 1 with a focus on potential risks for a more effective SCRM. The additional and verifiable information gained by blockchain implementation throughout the supply chain can result in various findings. For example, it might help to identify geographic concentration of production resources, logistical dependency on certain companies, or other risks not visible earlier.

The paper "Big Production Enterprise Supply Chain Endogenous Risk Management Based on Blockchain" investigates this approach in industrial supply chains. It concludes that while blockchain adoption might be not helpful to discover exogenous risks, it states that endogenous risk detection can be improved and implementation of DLT is reasonable and feasible [21].

As of March 2022, we can also see first real-world adoptions of blockchain technology in SCRM, especially in the agri-food sector. For example, IBM FoodTrust is one implementation of that use case. It enables retailers to connect their whole supply chain to a private blockchain. If a food safety issue is reported, it is immediately clear who caused the problem and what products are affected.

3.2. Process and Decision Automation

As the use cases focusing on better data visibility from chapter 3.2 have been presented previously, this chapter is going to give an overview of cases that interact deeper with the supply chain functionality.

3.2.1. Status Quo and Problems Today

Many processes along the supply chain are still often very manual, having only a low level of automation. This low level of automation can be traced back to two main reasons. Firstly, as analyzed earlier, supply chains' complexity increased over the last years, with many steps and stakeholders added. Secondly, regulatory authorities often still require a large amount of manual documentation.

The low level of automation does not only result in high opportunity cost. Another big problem is false information or inaccurate data. Research suggests that 10% of freight invoices contain inaccurate data which ultimately lead to disputes and further process inefficiencies along the supply chain [22]. Therefore, automating processes along the entire supply chain is an interesting category of use cases, of which two examples are going to be presented in the following.

3.2.2. Use Case 3: "Automatic Creation of Documents"

The first presented use case refers to the automatic creation of documents. Trade in general, but especially international shipping requires a lot of documentation. The most important document is thereby the Bill of Lading (B/L). This document can be seen as the main contract between the exporter and importer. Also, it states all relevant terms and conditions agreed-upon. In modern shipping, it also acts as trigger for payment cycles and has further information based on legal requirements. In most cases, B/L are still print-out papers that require wet signatures for relevant milestones. The administrative costs of this B/L creation and updating is estimated to make up 37% of the total freight forwarder fees [24].

The paper "Addressing some of bill of lading issues using the Internet of Things and blockchain technologies: a digitalized conceptual framework" introduces one way to completely automate all B/L-related processes. Therefore, containers and shipping gates are being outfitted with IoT technology, especially sensors and internet connectivity, so that devices can communicate directly with each other and without an intermediary.

Afterwards, a blockchain with five key components is being implemented. First, a privacy protocol cryptographically hashes all relevant data submitted through the supply chain. Second, a transaction ledger creates transaction when pre-defined milestones (e.g., arrival of a container in the harbor) are achieved. Third, a consensus mechanism verifies the authenticity of the suggested transaction. If approved, the transaction is being added into a block. Fourth, smart contracts are being triggered by the transactions and enforce agreed-upon terms, like the payment in cryptocurrency from wallet A to wallet B. Finally, whenever a transaction is completed, blocks are being added to the blockchain.

Regarding real-life implementation it is notable that this is not only a theoretical approach but has already been implemented by many different companies. Besides in-house solutions of large shipping companies, some start-ups around the world have emerged to offer an electronic bill of lading on a blockchain basis as-a-service, one of them being Slovenia-based start-up CargoX. Its product is built-upon Ethereum and offers the digitization of various types of freight documents, a full-text search across all documents, validation of the original source and prove of ownership, as well as a customizable interface [24]. CargoX raised $7m via an Initial Coin Offering (ICO) in 2018, however newer financial data is not available [25].

3.2.3. Use Case 4 "Automatic Coordination and Revenue Sharing"

Instead of only focusing on automating certain process elements to increase visibility and reduce operational costs, blockchain implementation can also be used to automate decisions across the entire SCM. The paper "Intelligent Smart Contracts for Innovative Supply Chain Management" suggests an approach that automates both, supply chain coordination in terms of supplier selection, as well as a fair ex-post revenue sharing. The goal is to create a framework that pre-defines all necessary criteria. Decisions are then being shifted away from the supply chain coordinator and are being made by the respective smart contracts.

To share revenue in a transparent way, a smart contract is being set up including a revenue sharing algorithm, following five steps. First, it calculates the average unit cost c_{sme} each member must bear within the supply chain. Second, for each resource, a minimum possible cost of competing suppliers ck_{min} is identified. As soon as the smart contract gets triggered, the algorithm distributes ck_{min} to all suppliers. Then, alignment costs are being distributed. These refer to expenses that occur for a single supplier to align with the greater interest of all supply chain members. Finally, the remainder is being shared as profit among all participants by a pre-defined clearing key.

The second part introduced by the paper is the automated supply chain coordination. Therefore, the originator firstly initializes the process by predefining all criteria on the blockchain. These include the product criteria, such as required parts, quantity, quality, delivery methods, and deadlines, as well as the overall profit and clearing keys for all parts, and finally the deadline for bids from suppliers. When all information is published on the network, suppliers can start to place bids. Finally, when the deadline has passed, a smart contract gets triggered that formally places all orders at the suppliers.

Overall, the blockchain-based network automates the manual process of finding the best supply chain partners. It offers clear advantages to the currently obscure bidding processes for all participating parties. This part was now investigated with a focus on the originator. If we imagine a system where the bidding process is also being automized, e.g., by smart contracts that bid automatically when certain conditions are met from supplier side, we can imagine how this network creates completely new supply chain designs that manually were not to be emerged.

3.2. Sustainability & Governance

This chapter is going to give an overview of how DLT can be used to create improvements regarding sustainability goals. Therefore, a short overview of the current situation is given as well as deep dives into two use cases.

3.3.1. Status Quo and Problems Today

Companies nowadays are facing the pressure from multiple stakeholders to ensure their business operations are meeting modern Environment, Social & Governance (ESG) standards. On the one hand, consumers are paying more and more attention regarding sustainability when choosing products to buy [26]. On the other hand, investors are looking closely on the ESG performance of their assets and are willing to pay a premium for socially responsible investments [27].

One major problem when looking at ESG performances is however information availability and trust. As Goldman Sachs points out in an article, a significant amount of ESG data on companies are self-reported making it difficult to objectively compare the information [28]. Additionally, more and more concerns are rising regarding Greenwashing. Therefore, it seems logical that companies should investigate whether new technologies can help to make their ESG data better comparable and more meaningful. In this chapter, two use cases are presented that do increase ESG performance by applying DLT to their operations.

3.3.2. Use Case 5: "Real-time Emission Reduction in Supply Chains"

As described in the previous use cases, blockchain is a suitable technology to increase visibility and transparency along the supply chain. This use case applies data from the blockchain to feed an algorithm to reduce carbon emissions.

This blockchain-based system was presented in the paper "A blockchain-based approach for a multi-echelon sustainable supply chain" and later-on tested by a simulation. Therefore, an exemplary supply chain having suppliers, manufacturers, distributors as well as a central manager controlling the entire chain was designed. Within that framework, an algorithm was developed to include all relevant data inputs, such as inventory, labor, and transport costs. Additionally, carbon emissions were converted to a monitorial value to conduct optimization with one variable only. The system then follows a 3-step approach.

1. In the "Initializing Phase", a first optimization is being done by inserting all available data points as input for the algorithm. The outputs, including Economic Order Quantity (EOQ) for each outlet and inventory storages, are being uploaded to the blockchain. Additionally, carbon threshold limits are being determined, quantifying the maximum allowed carbon emission per product.
2. The "Intervening Phase" is the part where blockchain technology is especially needed. Real-time data is being uploaded to the blockchain and emissions per product piece are being constantly calculated. If a limit of a certain outlet is being reached, a smart contract triggers the main system to start the "Optimization Phase".
3. In this third phase, all new data points are being downloaded from the blockchain and the algorithm is being executed with the updated information. As soon as a new optimum is being found, the instructions are being updated in the blockchain and the "Intervening Phase" starts again.

To give an example how this system might reduce CO2 emissions, imagine a factory in Malaysia having higher energy costs than expected because the weather is warmer than the annual average. If emissions are exceeding the pre-defined limits, the algorithm is going to investigate whether using another factory in China for the next batch has a lower emission cost, thus lowering overall carbon emission and creating an overall more environmentally friendly supply chain.

In a simulation using so-called MATLAB software, this system was compared to a standard supply chain optimization using a NSGA-II algorithm [29]. Different CO2 prices were tried out, and the blockchain approach could outperform the industry standard by reducing emission cost on average by 2.58%. Additionally, overall operational costs were lower in all cases independently of order demand. It is however important to note that this simulation cannot reflect real-world complexity. Therefore, the results should be seen rather as a proof-of-concept than a real validation of the superiority of the blockchain-based system [30].

3.3.2. Use Case 6: "Creating Traceable Circularity in Supply Chains"

As the concept of Circular Economy (CE) is a growing trend, current research is investigating the necessity for Circular Supply Chain Management (CSCM). Even though the terminology and the boundaries of CSCM are not clearly defined yet it becomes evident that the sector is driven by two main visions: firstly, the goal of a zero-waste economy, and secondly the generation of restorative and regenerative production cycles [31].

The basis of this chapter is an approach presented in the paper "E-waste Management Using Blockchain based Smart Contracts". However, certain adjustments have been undertaken. Firstly, the system is being generalized from a focus on the Indian recycling eco-system to fit for a global implementation. Secondly, a credit system is introduced that creates financial incentive for recycling, thus eliminating the need for penalties from governmental agencies as proposed in the paper. Thirdly, the conclusion to circularity of the entire supply chain is being conducted and presented. Lastly, an overall score was created to give consumers further insights about the level of circularity of a respective product.

The first step in this adopted approach is to bring all stakeholder on the same blockchain network, including the implementation of smart sensors to track activities and interfaces for users. The stakeholder in this process are the producers, the retailers, the consumers, the collection centers as well as recycling units. The second step is that smart contracts are being developed that allow the assignment of a unique ID to every product in the supply chain. Additionally, a credit score is being calculated. This score is being generated by the value of the raw materials within the product, multiplied by a certain factor larger 1. The larger this factor is, the higher the incentive for all supply chain stakeholders to participate in the entire recycling process. However, a higher factor also leads to a higher purchasing price for the final customer, potentially lowering the attractiveness of the offer. The third step happens through the entire product-lifecycle. To ensure the product does not only make it to the customer, a credit score has to be paid whenever the product changes its owner. Therefore, the retailer pays the producer, and the consumer pays the retailer (step 1 and 2 in figure 3). As the product is not used anymore, the user can give it back to the retailer, thus receiving back his money. The retailer can afterwards return the product to the producer, who is responsible for the follow-up recycling process. All payment processes are automated with smart contracts, giving all parties the certainty that credits are going to be paid back. The exact process is modelled in figure 3, showing all physical and financial transactions.

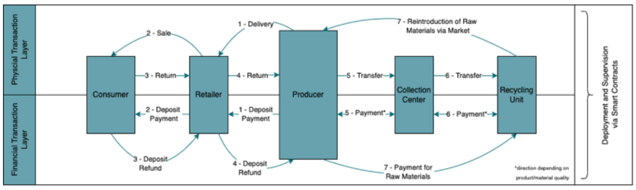

Figure 3: Proposed Circularity of Use Case 6. Own Representation.

Additionally, as all product transactions can be non-alterably traced ex-post, a score can be calculated in real-time, showing the degree of recycling every product has. For example, a shoe designed in a way that a lot of resources could be recycled in the past receives a good score that could be used for marketing purposes.

While this exact approach has never been implemented, also because it was partly modified in this paper, similar approaches have been conducted already. The US-based specialty chemicals manufacturer Eastman Chemical has developed a blockchain network together with German software company SAP that can certify products with an exact percentage of recycled materials used in production as well as a tracking of that process over time. According to Eastman Chemical, this project has the potential to "be a turning point for the circular economy" [32].

4. Discussion of the Findings

4.1. Blockchain Implementation in Supply Chains Today

According to the analysis conducted in chapter 3, two main categories of blockchain penetration depths could be found. First, low-level use cases, focusing on increased visibility and low-level process automation can be seen. This category includes use case 1 and 3 of this paper. The technology of blockchain in these cases are seen as a tool to enable an evolutionary progress. However, the technology does not really change the way supply chains are designed or decisions are being made. Therefore, it cannot be seen as a revolution within Supply Chain Management.

The second category however refers to higher-level use cases, such as cases 2, 4, 5, and 6. Here, the increased visibility and transparency enabled by DLT is used to create deeper interference with the management of supply chains. Therefore, decisions, like the process of choosing the best manufacturer, are being shifted away from single supply chain stakeholders and are instead exercised by pre-defined conditions within smart contracts. This category is indeed to be seen as revolutionary, as it transforms supply chain design and shifts power from stakeholders to the technology.

Looking at real-world implementations, it is noticeable that many companies did already implement pilots of the lower-level use cases. By just increasing visibility and automating low-level processes, companies can try out the possibilities of the technology and build up internal blockchain competences, without risking a falsely implemented smart contract to result in the malfunction of a supply chain. The higher-level use cases however only start to emerge in the real world. Scientific papers are already proposing specific instructions of how the technology might be implemented and simulations being conducted to understand the implications, and it is to be expected that more and more real-world implementations of these ideas are to be seen in the next years.

4.2. Identified Problems & Concerns regarding Blockchain Implementation

The reason why real-world implementation, especially of higher-level use cases, are however slow to emerge is because even though possibilities are promising, companies are also facing a lot of challenges. To better understand the barriers of real-world adoption, the TOE-framework, developed by Tornatzky and Fleischer in 1990 is going to be used.

Firstly, technological problems occur within blockchain implementation. A big challenge are thereby security challenges, such as 51% attacks on smaller networks and endpoint vulnerabilities from user interfaces and APIs. Additionally, the immutability of blockchain does also create challenges. It is difficult to impossible to change data within blocks, even though if false information has been uploaded. Thirdly, according to a representative study by the World Trade Organization, Standardization, Interoperability and Integration to back-office systems are a big hurdle for real-world implementation [33].

The second dimension of the framework refers to all environmental problems. Firstly, legal and governmental uncertainties are a huge problem. While different countries indicate different approaches regarding future legislation of crypto projects [34], also current laws are partly in conflict with DLT. Article 17 of Europe's GDPR states the so-called "Right-to-Forget", meaning companies must delete user data on request. It is however unsure how this can be done for date stored in blockchains.

The last dimension investigated are organizational problem. Thereby, a lack of management expertise and commitment can be observed [35]. This means that decision makers are not fully aware of the possible implications DLT might offer. Adding to that, the high implementation costs of blockchain developments lead to a lower motivation to implement DLT projects.

4.3. Possible Implications for the Future of Supply Chains

While it is difficult to predict and quantify the exact degree of innovation DLT is going to bring to the logistics sector, it is safe to say that some parts of it are going to be evolutionary or revolutionary influenced by the technology. All presented use cases that conducted a simulation or real-world comparison of the proposed implementations could see efficiency gains and therefore value creation compared to the Status Quo. Also, the rising number of crypto-startups and their successful financing rounds show that various parties believe in the financial success of DLT. Based on the analysis of this paper, three assumptions can be made regarding possible implication on Supply Chain Management:

1. DLT can digitize, automate, and enhance processes in a way earlier technologies were not able to. As analyzed earlier, the complexity of supply chains leads to a situation where white spots regarding automatization can still be found in many places, for example the wide use of paper and wet signatures for the B/L process. The analysis suggests that these white spots will be automated by the implementation of DLT soon.
2. DLT has the possibility to solve basic and structural challenges that have been around in Supply Chain Management for decades. For example, the well-researched bullwhip effect could be significantly reduced. By automating order and prediction processes with smart contracts, the amplification of highs and lows can be reduced. Looking at the contract theory, we can explore a second example. The Grossmann- Hart-Moore model of contract incompleteness states that at the time of contract signing, not all future events can be predicted, thus leading to a deviation from the original agreement at some point of time [36]. With the introduction of smart contracts, that are being pre-defined and are non-changeable afterwards, the degree of contract completeness could be increased.
3. It is to be expected that legislation is going to follow innovation. Theoretical research and practical pilots are already showing today the effectiveness of the technology, therefore putting pressure on governmental bodies to create an environment this innovation can thrive. In the blockchain world, this could be seen already in a financial context. The German authority for financial supervision, Bafin, created a legal environment for crypto-based security token offerings (STO) to enable innovative corporate financing models with a safe legal frame [37].

5. Summary and Take-Aways

To assess the potentials of blockchain technology, this paper first gives an overview of important concepts and currently available implementation options. Thus, the differences between centralized, decentralized, and distributed computing as well as blockchain technology are explained. Afterwards, in chapter 3, a deep dive into six use cases is undertaken. The paper finds that these cases can be categorized regarding their implementation depth into low-level and high-level use cases, that differ in implications for the supply chain design. Afterwards, technological, environmental, and organizational problems are presented that explain why blockchain technology is only starting to emerge. Many concerns and questions remain unanswered today, thus, creating a need for further research as well as entrepreneurial action, additionally underlining the importance of combing theoretical and practical approaches for this young technology.

The main question to be answered with this paper is whether and how DLT can be used to overcome existing problems in Supply Chain Management and to create additional value for its stakeholders. The main advantage blockchain is enabling is the increased visibility, trust, and certainty for all supply chain members. However, the implications of using these advantages go far beyond that. The analysis shows that the implementation of distributed technologies can increase supply chain resilience and improve their design. Additionally, different approaches are presented that proved in simulations and pilots that value creation through blockchain implementation does work. However, while promising, the technology cannot be expected to solve all supply chain-related problems. More and more interconnected economies, the effects of JIT manufacturing, and the consequences of geopolitical events are not going to be solved only by automating certain processes with DLT. Thus, to create sustainable, secure, and efficient supply chains that meet the economic and political goals of the next decades, blockchain and DLT can only be seen as one piece that needs to be set and seen in the bigger context.

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