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Will Blockchain Technology Revolutionize Supply Chain Management?

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ABSTRACT

Purpose: The purpose of this paper is to assess if blockchain technology, which is hailed for its potential to improve supply chain transparency and efficiency, can deliver to this promise (Abreu et al., 2021; Mahyuni et al., 2020; Manzoor et al., 2022; Rennie, 2022; Yiannas, 2018). Supply chains are increasingly complex and full transparency is difficult to achieve and may sometimes be undesired, yet governments worldwide are demanding more transparency especially with respect to the social and environmental sustainability of supply chains (Francisco & Swanson, 2018; Franke, 2021; Najjar, 2021). If blockchain technology allows to close this gap, without compromising corporate confidentiality and efficiency requirements, it might change supply chain management drastically. Most other research in this field remains rather superficial with respect to the fundamentals of blockchain technology and supply chain management. Our study will add to the very limited theoretically founded research on blockchain potentials in supply chains.

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Study Design: Our paper is conceptual. Based on the extant literature, we compare blockchain technology and its advantages to the characteristics of supply chains and challenges of supply chain management to identify a theoretical fit. We investigate if published case studies of blockchain technology in supply chain management support this. Finally, we devise a conceptual framework for the application of blockchain technology in supply chain management.

Findings: There is, currently, very limited use for blockchain technology in supply chain management. It does not provide an answer to several of the challenges that exist in supply chain management. Blockchain technology was primarily devised as encryption technology for virtual entities and transactions involving them and not for tangible objects. Published case studies describing the use of blockchain technology in supply chain management do not contradict these findings.

They rely on private blockchain solutions lacking the key benefits of blockchain technology. Our conceptual framework constitutes a reference for a future public blockchain solution for supply chains. It offers solutions for some of the challenges but also cannot solve some fundamental challenges, like power imbalances in supply chains.

Limitations: Blockchain technology undergoes rapid development. Future blockchain technology may be faster, less energy-intensive and more integrated with other technologies. This may be aided by developments in hardware, like quantum computing. The findings of this paper are limited to currently available technology.

Implications: Companies and governments alike should be very cautious when considering investing in currently available blockchain solutions for supply chain management.

Keywords: *Blockchain, Technology, Supply Chain, Management, Transparency, Sustainability*

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1. INTRODUCTION

Most of the extant literature is very optimistic that blockchain technology can have a big impact on supply chain management and even revolutionize supply chains (Pournader et al., 2020). In particular, it is suggested that blockchain technology can be used to track products throughout the supply chain, thereby helping to achieve sustainable supply chains and protect against product counterfeits (Mahyuni et al., 2020). Furthermore, blockchain would reduce the need for trust in supply chains (Keller, 2022). All documents could be handled through the blockchain (Alicke et al., 2017; Durach et al., 2021). Overall, blockchain might lead to more cost-efficient supply chains. (Mahyuni et al., 2020). Very little empirical research in this topic has been done to verify the potentials of blockchain technology (Manzoor et al., 2022). Rather few authors (Alicke et al., 2017; Bischoff & Seuring, 2021) question the suitability of blockchain technology for supply chain management.

Bischoff and Seuring (2021) focus in their paper on the application of blockchain technology for supply chain traceability and despite all criticism with regards to existing blockchain implementations they conclude that the technology has "disruptive potential" for supply chains. We aim to extend Bischoff and Seuring's research, widening the focus on sustainable supply chain management in general, and rephrasing the research questions as follows:

1. What characteristics of supply chains limit blockchain technology in supporting supply chain management?
2. Under what conditions might public blockchain solutions be able to support supply chain management?

In our paper we summarize the key characteristics and benefits of blockchain technology. We then assess the compatibility of blockchain technology and supply chain management and attempt to verify these findings reviewing published case studies. Finally, we derive preconditions for the application of blockchain technology

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in supply chains and summarize these in our conceptual framework for the application of public blockchain to supply chains.

2. BLOCKCHAIN TECHNOLOGY

Our brief description of blockchain technology in the following is structured according to the Quality Function Deployment method (Akao, 2004). The benefit of using Quality Function Deployment is the clear distinction between WHATs (What the customer values) and HOWs (how this is achieved by the product or technology in question). The approach is normally used to focus attention in product development on those HOWs which have the biggest impact on those WHATs which the customers most value. In our research we primarily use the method to distinguish WHATs clearly from HOWs, which is in the previous literature not always done. Fig. 1 summarizes how WHATs and HOWs are related, a "+" indicating an expected positive relationship. The WHATs form the basis for the assessment if blockchain technology would be beneficial to global supply chains.

3. HOW IT WORKS (THE HOWS)

Blockchain technology has now been in use for almost 15 years for cryptocurrencies, but goes back to a publication by Stuart Haber and Scott Stornetta (Haber & Stornetta, 1991; Skwarek, 2019). It is based on distributed ledger technology and the principle of peer-to-peer networking and can be described as a decentralized database system, which enables its users to verify and store data (Skwarek, 2019; Wittenberg, 2020). The individual network nodes in a decentralized system can connect to each other and communicate without a central instance (Wittenberg, 2020). A peer-to-peer network is a special form of decentralized network. In a peer-to-peer network all network nodes have equal rights and status (Meinel & Gayvoronskaya, 2020). In the peer-to-peer network underlying the blockchain, each of the network nodes stores a copy of the blockchain (Urban, 2020). In order to make a change to the blockchain, consensus of the majority of the network nodes involved is required.

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To add a new block to the blockchain, a so-called hash value must be calculated. This hash value is composed of the hash value of the previous block, the transactions, a timestamp and a random number, the so-called nonce. The calculated hash value must also contain a specified number of leading zeros (Urban, 2020). New blocks are created by so-called miners who verify the transactions they contain and are paid for the work they perform (Brühl, 2017). Miners are either qualified to do this by "proof-of-work"-mechanism, where they have to solve a complex mathematical puzzle or by "proof-of-stake", where the network selects a miner based their stakes in the blockchain (Fridgen et al., 2019).

4. ADVANTAGES OF BLOCKCHAIN TECHNOLOGY (THE WHATS)

The key benefits of blockchain technology resulting from the above characteristics are described in the following and summarized as "Whats" in Fig. 1:

Transparency

The information which is stored in a public blockchain is publicly accessible. Everyone can view current and past transactions. It is also transparent who performed them. Some level of privacy is obtained by identifying users with public keys rather than names (Schlatt et al., 2016).

Traceability

As all new blocks are linked to the previous block, entities whose ownership is administered through the blockchain can be traced all the way back to their origin. All transfers of ownership of one particular entity are recorded. This is particularly helpful where those who engage in transactions have no reason to trust each other (Keller, 2022).

Immutability

All blocks are timestamped and linked to another. To change these blocks, network consensus would be required. It is therefore impossible to manipulate the data in the blockchain unnoticed (Urban, 2020).

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Data Security

Data Security is achieved through encryption of all information that is stored in the blocks, through public and private keys. Data Security is further enhanced by storing the entire blockchain on a large number of network nodes and by using miners to verify transactions and calculate new blocks (Jostock, 2019; Schlatt et al., 2016).

Speed

The decentralized nature of the distributed ledger technology means that information is available without delay on each node (Pournader et al., 2020). On the other hand, mining requires some time, and hence the speed with which new transactions are written in a block and added to the blockchain is sometimes criticized for being slow (Abreu et al., 2021; Coppola, 2016).

Efficiency

Blockchain technology is claimed to be efficient as it operates without central authority. Cryptocurrencies however are increasingly criticized for their energy requirements for data storage and mining (Abreu et al., 2021).

Fig. 1 – QFD Matrix for Blockchain Technology

Whats / Hows	Decentralisation / Public Distributed Ledger	Timestamped Hashed Encrypted Blocks, irreversably linked to one another, standard transactions	Disintermediation/ Network Consensus	Proof of Work or Stake /Mining
Transparency	+			
Traceability		+		
Immutability		+	+	
Data Security	+	+		+
Speed	+			
Efficiency			+	

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5. TYPES OF BLOCKCHAIN

There are two types of blockchain, public (or permissionless) blockchains and private (permissioned) blockchains (Blossey et al., 2019). They differ in how the permissions (read, right and consensus permissions) are distributed (Meinel, 2020). In a public blockchain there is no restriction on permissions for anyone. All information is public. Anyone can engage in transactions and mining. In a private blockchain, permissions can be restricted by a central instance. A consortium blockchain is another form of private blockchain, where several parties jointly administer the blockchain (Manupati et al., 2020).

Because of their decentralised nature, public blockchains offer a high level of security and immutability as well as a high level of transparency while retaining a certain level of anonymity to users, but this is also associated with lower transaction speeds and high energy consumption (Treiblmaier, 2019). Private and consortium blockchains, on the other hand, are more efficient and have a higher transaction speed but do not offer the transparency and immutability of data of public blockchains, both key benefits of blockchain technology.

6. USE OF BLOCKCHAIN TECHNOLOGY FOR SUPPLY CHAINS

Najjar (2021) describes in principle how blockchain technology, might be used to support supply chains. The idea is that all transactions related to a product and possibly additional data, e.g. regarding sustainability, are recorded in the blocks of a blockchain. In the following, we assess if the benefits of blockchain technology which were described above, can have a positive impact for supply chains, when blockchain technology is implemented in this way.

Transparency

Transparency of supply chains is more and more required by consumers/ lawmakers (Kshetri, 2018). For companies that are required by law or customers to provide this

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transparency it is often not easy to obtain full transparency of their own supply chains themselves (Nager IT, 2021). The public often underestimate the complexity of supply chains. They may be simple for some food and beverages. For many other products however, they are a lot more complex (McGrath et al., 2021). They are complex with regards to the number and variety of elements, the type of interactions, dynamism, uncertainty and non-linearity (Serdarasan & Tanyas, 2012). Supply Chains are in fact not chains but better described as networks. Also, supply chains have no start and end but must be seen as circular, more and more so due to recycling requirements.

Apart from these general difficulties in achieving supply chain transparency, while transparency may be desired from a consumer point of view, companies will not want to disclose their purchasing and sales volumes for raw materials and products (Bischoff & Seuring, 2021; Paliwal et al., 2020). Likewise, not all players in supply chains have an interest in making their sources transparent. Supplier selection is a source of competitive advantage. And since power is distributed unevenly in supply chains, customers are not always be able to force their suppliers to disclose their sources (Essabbar et al., 2020). Blockchain technology as such cannot change these underlying problems of supply chain transparency.

Traceability

Traceability goes beyond transparency in that you can trace individual items back to their sources (Bischoff & Seuring, 2021). Tracing items in supply chains is common practice. Consumers are used to track and trace consignments from where they were dispatched. Also, in certain industries like aerospace and pharmaceuticals, regulators demand full traceability of the parts and ingredients of products. For most supply chains, however, direct partners are known and trusted, relationships are governed by contracts, often over a longer term, supply sources are seen as trade secret, and thus tracing items beyond first tier suppliers is uncommon (Alicke et al., 2017).

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Compared to cryptocurrency, the main challenge is that in supply chains, ownership of physical items is transferred (Francisco & Swanson, 2018). So, while the network can verify if a company obtained ownership of an item before selling it, it is difficult to verify if the physical item has been exchanged against another from a different source. Also, the physical items change their appearance and they are combined with other items in the process, which makes traceability more complex. Furthermore, there is a multitude of data standards in supply chains which makes tracing transactions difficult (Keller, 2022).

Immutability

From a consumer and regulator point of view, data immutability is desired. However, the value of immutability for supply chains is questionable, as sometimes data in supply chains needs to be changed (Bischoff & Seuring, 2021). It also does not protect against an exchange of physical items, as described above.

Data Security

Data security is of high relevance for all business. The basic encryption mechanism used for blockchains, however, can also be used in client-server-solutions. The detailed mechanisms (consensus mechanism, mining) only make sense in combination with the idea of logging a large number of transactions in a chain of blocks. Operational management of supply chains, will likely require other systems besides a blockchain that provides traceability, hence data security in blockchains is unlikely to be the reason to move towards blockchain solutions (Saad, 2019).

Speed

The speed at which new blocks are created and transactions added to the blockchain does not have to be as high as for cryptocurrency, since the transfer of the physical product will in most cases require some time. Speed is therefore not a convincing reason to use blockchain technology for supply chains.

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Efficiency

Data Volumes in Supply Chains are much higher than currently for cryptocurrencies which are already criticized for their energy requirements. All supply chains are intertwined in some way or another, thus all data of all supply chains would have to be stored in one big blockchain, even though it is questionable also if it makes sense to record totally unrelated supply chain transactions in one blockchain, stored on a huge number of nodes. Such a blockchain solution would be neither efficient nor fast (Alicke et al., 2017).

7. REVIEW OF CASE STUDIES

To verify the above findings, we examined five well-documented case studies of blockchain applications for supply chain management from the automotive industry, food industry, diamond industry and from pharmaceuticals. Various other case studies are known (Behnke & Janssen, 2020; Blossey et al., 2019) but the vast majority are not publicly available or not as well documented. During the research, we took care to examine case studies from different sectors in order to obtain a broader picture of the application of blockchain technology in supply chain management.

Volkswagen AG & Minespider

In collaboration with the company Minespider, the Volkswagen Group aims to use blockchain technology to make its lead (Pb) supply chain more transparent and ensure the traceability of the raw materials used back to their origin. It also aims to ensure that the raw materials required for production are procured in a fair, socially and environmentally responsible manner. Another objective is to eliminate sources of error within the supply chain and optimize supply chain risk management. (Horch, 2019; Volkswagen AG, 2019; Williams, 2019)

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Bumble Bee & SAP

The U.S. food manufacturer Bumble Bee Foods and the German software company SAP have developed a blockchain-based solution for Bumble Bee's tuna supply chain. The aim is to make the tuna supply chain more transparent, ensure product traceability, improve communication within the supply chain and increase sustainability. (Joo & Han, 2021; SAP, 2016)

Walmart

Walmart is trying to improve the traceability of mangoes from end customer to farmers with the help of blockchain technology. Walmart is hoping to improve food safety and increase transparency, sustainability and supply chain efficiency. (Hyperledger Foundation, 2022; Joo & Han, 2021; Yiannas, 2018)

De Beers

De Beers Group is using blockchain technology to ensure the traceability of diamonds from the end customer back to the point of origin. This is to ensure that the diamonds sold are not conflict diamonds. In addition, the owner of the diamond should be able to prove the authenticity beyond doubt. (De Beers Group, 2022; Smits & Hulstijn, 2020; Verny et al., 2020)

FFF Enterprises

A case study from the field of pharmaceuticals is provided by FFF Enterprises. The goal of implementing blockchain technology is to streamline the procurement process, eliminate pricing errors, eliminate chargeback disputes and increase efficiency. (FFF Enterprises, 2021)

All case studies are similar in that the aims of the implementation are to improve transparency and traceability and to document the sustainability of the supply chain in question. We also found that all these case studies of blockchain implementation in supply chain management describe the use of a private or consortium blockchain,

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therefore lacking the full benefits of public blockchain solutions, especially immutability. In those cases where the public is granted reading access to all transactions in the blockchain, while true immutability is not given, it would at least be visible to the public if any information in the blockchain was changed ex post. The supply chains for which blockchain technology is used are rather short and the company which implemented it is in a rather strong position in the supply chain. None of the case studies offer a solution to the problem that transactions in the blockchain are related to physical objects and therefore there is no protection against the physical goods being exchanged against others from a different source. A further problem that is not addressed is that since supply chains are intertwined, the companies would in the future either need to work with several blockchains or agree on one solution for all.

8. CONCEPTUAL FRAMEWORK

Based on the above findings we have devised a conceptual framework for the use of a public blockchain for supply chains (Fig. 2). The purpose of the blockchain in our framework would be mainly to document transactions and to provide traceability, very much like in the published case studies. There would need to be other systems used in parallel to place purchase orders, payments etc. Recording additional information, e.g. related to sustainability, in the blockchain may be possible but would further increase data volumes.

As all supply chains are intertwined in some way, the framework relies on a single blockchain for all supply chains. This would allow consumers or legislators to trace all products through a single blockchain. The blockchain would have to be set up by an organization (similar to the world wide web consortium) that sets data standards for the blockchain. For the public to be able to trace products through this blockchain, it is necessary, that all companies involved in the supply chain of the product in question participate.

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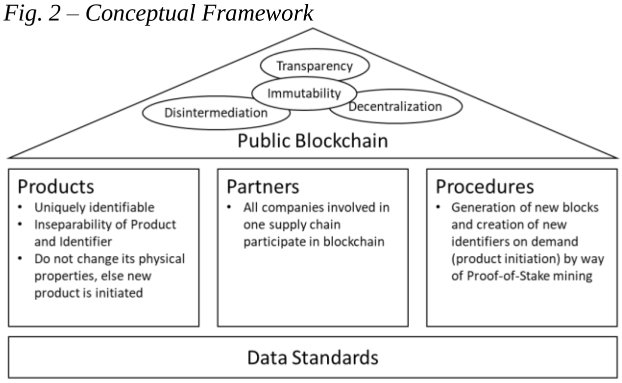
As discussed above, the resulting data volume from having one single public blockchain will be substantial. A possible solution might be that not the entire blockchain is stored on all nodes but segments of it on multiple nodes. This is called "sharding" (Avarikioti, 2021). It is also possible that in the future there will be a technological solution able to deal with higher data volumes efficiently.

As complex mining procedures for new blocks are costly and energy consuming and since the data stored is not as valuable as for cryptocurrencies, we suggest that new blocks are created through proof-of-stake mining from new transactions, timestamp and the hashtag of the previous block. The validity of new transactions, which mainly involves verifying that a party selling an item previously obtained ownership of this item, would be checked in this process.

It will only be possible to track goods and products that are uniquely identifiable and do not change their physical properties. It must be impossible to separate the product from its identifier, so that the data in the blockchain always relates to the exact same item. If a product changes its physical properties the chain for this product needs to end and a new product has to be initiated. The initiation of new products would require that a new product identifier be added to the blockchain. The blockchain system would, when demanded, in the mining process generate a new identifier for the product. The number of new items registered in the blockchain cannot be limited like cryptocurrency coins, hence the complex mining procedures which are required for the creation of new coins are not required.

Fig. 2 – Conceptual Framework



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9. DISCUSSION

In our conceptual framework we formulate prerequisites for blockchain technology to provide transparency of supply chains. In this form, the supply chain blockchain would have all advantages of a public blockchain. We do not evaluate how realistic it is that these prerequisites will ever be met.

Arguably the biggest challenge is the required inseparability of product and product identifier. For products where this criterion cannot be met, the use of blockchain technology is questionable. Also, according to our framework, as soon as a product changes its physical properties, this would have to be treated as a new product. Depending on the type of product the resulting "chains" may be very short, making the use of complex blockchain technology questionable.

We have explained that some companies (and countries) may not like the transparency given by blockchain technology and that due to power imbalances they often cannot be forced. In these cases, blockchain implementation makes no sense. We cannot offer a solution to prevent sensitive information, like sales volumes, from being visible to the public. This might be less of a problem for companies that sell multiple products, but for a company that only has one product the transparency of a blockchain would mean that all sales volumes are made transparent.

There also needs to be a mechanism to prevent abuse, like unnecessarily requesting large numbers of product identifiers. One way to deal with these challenges would be to let the organisation that sets up the blockchain also administer access rights. The blockchain would in that case no longer be a true public blockchain but more similar to a consortium blockchain, lacking the benefits of disintermediation. It would be critical then, that all potential users of the blockchain trust this organisation.

10. CONCLUSION

In this paper, we investigated the benefits of an application of blockchain technology in supply chains. We presented the basic mechanisms of blockchain technology and described its advantages. We then assessed if these advantages are valuable in a supply chain context and found that there are major challenges in supply chains that will make the use of blockchain technology questionable. Published case studies of blockchain adoption in supply chain management do not contradict this finding. We developed a conceptual framework that describes, under which conditions blockchain technology might help achieve transparency and traceability in supply chains. It is

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questionable, however, if these conditions can be met. We therefore conclude that companies and governments should be very careful when investing in blockchain technology for supply chains.

Our conclusion has to be seen as preliminary, since blockchain technology is developing rapidly. Future research in sustainable supply chain management should therefore continue to consider blockchain technology as a solution, potentially in combination with other new technologies like the internet of things.

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