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Blockchain applications in the supply chain management in German automotive industry

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ABSTRACT

The automotive industry appears to be a particularly attractive application case for blockchain technology adoption. Blockchain is one of the innovations that has much potential to change current business processes in German original equipment manufacturers (OEMs) and enable new services for their customers. This paper combines collective case study and in-depth interviews to explore the potentials and existing challenges of blockchain technology-based applications at German OEMs. The results suggest that blockchain applications have advantages in aggregating product information, securing transaction information, and establishing a reliable supply chain. Based on the TOE (technology, organisation and environment) model, our case study shows that the biggest obstacles for blockchain technology adoption in the automotive supply chain include: technology immaturity, lack of guidance and industry standards, non-cooperation of chain members, and legislative ambiguity. Based on auto manufacturers investigated, blockchain technology is perceived to have great potentials in reducing process costs, ensure product quality, and enhance the automotive supply chain's visibility and digitisation.

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1. Introduction

A supply chain is a complex and comprehensive concept covering the entire production and distribution process from the raw material supplier to the end customer. Its primary goal is to create a network between different stakeholders to fulfil all customer needs and improve responsiveness. In a globalised economy, many industries are trying to maintain their competitive advantages by building efficient and global supply chains (Mol 2003).

An excellent example of this can be found in the automotive industry. In the past decades, the industry has repeatedly entered new markets and pushed further the process of specialisation. For example, large German automobile companies outsourced most production and R&D activities to upstream suppliers. This not only increases the geographical dispersion of the German automotive supply chain but also leads to the complexity of the automotive industry supply chain (Christopher and Holweg 2011). In addition, from business development and supply chain sustainability perspective, it has been repeatedly shown that many global supply chains have problems such as lack of information transparency, which easily lead to product quality uncertainties. Therefore, the entire information supply chain for automotive products must be further enhanced from raw materials to sale distribution.

Generally, the supply chain in the automotive industry is seen as less responsive, integrated, and visible than in other industries (Wissuwa and Durach 2021). The reasons for this are the complex structures of the supply chain and non-transparent transactions between entities in the supply chain, which leads to a lack of trust and coordination between supply chain participants. Already today, it can be seen that in the automotive industry, transparency, information sharing, and traceability are becoming key differentiators and are therefore essential for supply chains (Saberi et al. 2019). For this purpose, it is important to establish decentralised trust mechanisms and effective tracking systems to ensure information linkage among all supply chain partners (Kurpjuweit et al. 2021).

The distributed ledger model of blockchain enables various companies involved in transactions to act as nodes to achieve transaction security. The combination of blockchain technology and the IoT can effectively solve the challenges of traceability of materials throughout the automotive manufacturing process (McBee and Wilcox 2016). Importantly, blockchain technology requires the full participation of all companies in the supply chain (Crosby, Verma, and Kalyanaraman 2016), as this is the only way to strengthen mutual trust between companies and ultimately increase supply chain transparency. Although blockchain technology is a relatively new technology, the application of blockchain technology in the automotive supply chain is slowly getting investigated by many scholars. For example, Chen et al. (2020) introduced a blockchain-based financing platform for the automotive trade, which would make one part of the

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supply chain reliable, efficient, and secure. Bader et al. (2021) proposed to build a private information chain based on blockchain technology to achieve the information management of complex supply chains under dynamic business relationships. Due to the complexity and high number of companies, building a smooth and traceable supply chain will be the foundation for the development of the automotive industry. Therefore, a thorough investigation of Blockchain applications potentials and addressing practical challenges will help companies adopt advanced technologies and improve the sustainability of their existing supply chain.

Although previous research has made a valuable contribution to understanding the impact of blockchain on supply chains at a general level, it provides few empirical insights into the automotive supply chain. In particular, large-scale use cases beyond the pilot stage are still lacking, which is why the initial research findings relied mainly on theoretical concepts. We believe that the literature would benefit from actual case studies at this stage, as most of the research is based on theoretical discussions. Therefore, we use the collective case study method to investigate the application of blockchain technology in German OEMs that solve specific problems in the current automotive supply chain. The study identified the following research questions:

1. How is blockchain technology applied in the automotive industry, and what is its application potential?
2. What are currently the main challenges in adopting blockchain in the automotive supply chain?

We use a collective case study method to study the current application of blockchain technology used by German OEMs, and observed the technology adoption of different use cases through in-depth interviews and explored and identified the potential and barriers of blockchain adoption in detail. Practitioners and academics are invited to evaluate the key factors identified to ensure the robustness of the research. The findings offer insights into the emerging field of blockchain technology in operations and supply chain management and contribute to the broader discussion on emerging technologies in supply chains (Kache and Seuring 2017). In particular, we used the Technology, Organisation, Environment (TOE) framework to address the objectives of this study. Tornatzky and Fleischer (1990) believed that the process of an enterprises' adoption and implementation of technological innovation is influenced by three contexts: technological context, organisational context, and environmental context. These situational factors affected enterprises' value creation. Ultimately, it influences the performance of the innovation organisation (Zhu and Kraemer 2005). Therefore, the TOE model is a viable research framework for understanding the challenges of blockchain implementation in the automotive supply chain.

The remaining paper is organised as follows. Section 2 first reviews some related studies in the literature. The methodology, including the research design and analysis method, is presented in Section 3. Then, the current applications of blockchain technology for supply chain management in the automotive industry are presented in Section 4. Finally, Section 5 presents the conclusions and suggestions for future research directions.

2. Literature review

2.1. Supply chain management in the automotive industry

Compared with other goods, automobiles are expensive and complicated to manufacture, which results in high-quality expectations of the product quality by customers and the entire society. In the entire automotive manufacturing supply chain, in addition to the vehicle manufacturer at the core, there are several raw material suppliers and parts suppliers upstream whose product quality directly affects the safety and quality of the entire automobile. To ensure the quality and performance of automotive vehicles, the necessary quality monitoring and control are required in the automotive production supply chain. Due to the complex structure of the supply chain in the automotive industry (Christopher and Holweg 2011), the wide geographical distribution, the high dependence on upstream companies in the supply chain (Steven, Dong and Corsi 2014), and the long vehicle production cycle, building product traceability and trust mechanisms has always been one of the challenges of supply chain management in the automotive industry. This is reflected in the following aspects:

2.1.1. Traceability of products or raw materials

In recent years, there have been frequent recalls of automobiles due to quality problems. The quality problems of diesel engines, gasoline engines, airbags, and other important components (Jung and Elizabeth 2019) have caused serious risks to users' life and safety. However, in the case of integrated automobile manufacturing, it is difficult to accurately find the root cause and scale of the problem in a short period. The process of raw material traceability today is complex and inconvenient, and the cost of developing such a system on your own is very high. This results in a low traceability efficiency, which leads to poor visibility of automobile supply chain management and is susceptible to sustained damage.

2.1.2. Information sharing

The acceleration of globalisation will lead to a further increase in the complexity of the automotive supply chain, an increase in the number of participants, and an even wider geographical distribution of the supply chain (Luthra, Garg, and Haleem 2015). The components required for automotive production often originate from different countries, potentially leading to miscommunication of information between supply chain partners on logistics, costs, capital flow, and raw material quality (Kwon and Sung 2018). In addition, since some participants in the global supply chain have low data transparency and believe in strong confidentiality, information islands can easily occur. Such a lack of information availability can lead to consumers having doubts about the safety of products, especially automotive products with higher safety requirements. This will ultimately lead to inefficiencies in customer management, production management, quality management, and service management in the automotive supply chain.

2.1.3. Trust of partners in the supply chain

In the automotive supply chain, the number of companies involved is high, the interaction between suppliers is complex, and the production standards and product information between cooperating companies are not transparent, which makes it difficult for key OEMs to capture the actual information from suppliers. Due to the nature of this complex supply chain, the main challenges faced by all supply chain participants is to decrease product information uncertainty, information asymmetry, and increased transaction risk (Rogerson and Parry 2020). These potential problem characteristics lead to a serious lack of trust between enterprises up and down the supply chain. These characteristics highlight the fragility of complex supply chains.

To be able to make informed business decisions in a complex supply chain environment, a company has to use information technology to collect and analyse data from multiple sources throughout the supply chain (Abeyratne and Monfared 2016). Companies need to ensure that the information they receive is accurate and complete and has not been tampered with by any other partner (Wang, Han, and Beynon-Davies 2019). Based on this, establishing reliable information-sharing mechanisms, product traceability features, and information verification methods is a promising way to improve trust and performance throughout the supply chain (Kshetri 2018). Blockchain technology can be integrated into digital supply chains to guarantee inherent security, the immutability of information, transparency of transactions, and authenticity of data (Christidis and Devetsikiotis 2016), and thus act as a trust mechanism between participants.

2.2. Blockchain technology

Blockchain technology has no widely accepted definition, as the concept was first proposed in a white paper by Satoshi Nakamoto, who described the potential capabilities of his blockchain-based cryptocurrency bitcoin. He describes a proof-of-work blockchain that solved the long-standing double-payout problem that was previously inherent in any decentralised electronic transaction (Nakamoto 2008). Swan (2015) proposed that blockchain technology is a decentralised database with the characteristics of openness and transparency. The technical principle involves the cryptographic hash algorithm connecting the blocks to the previous blocks in chronological order. After that, the algorithm takes the previous block's hash value as input to the next hash function (Christidis and Devetsikiotis 2016). After the transaction has been consistently validated by one node and the information is distributed to most of the nodes in the network, the new block is added to the emerging chain (Swan 2015). Blockchain can build a decentralised, trusted system based on digital cryptography, information sharing, and consensus algorithms (Crosby, Verma, and Kalyanaraman 2016). In summary, from the perspective of network structure, blockchain is a distributed ledger (Choi 2019), while from the perspective of usage, blockchain can be a highly reliable store of value or a transparent list of different transactions.

Existing research shows that the key difference of a blockchain in regard to most centralised information system designs is that the blockchain contains the following key characteristics, such as decentralised information storage (Wamba et al. 2020), information invariability (Wolfond 2017), security trust mechanism (Razaket, Hendry, and Stevenson 2021), consensus/sharing mechanism. This makes blockchain technology an interesting technology for production, manufacturing, trading services. First, the underlying structure of blockchain technology can help information security and make data tracking easier and more reliable (Hastig and Sodhi 2020). The transaction blocks of the blockchain are connected in a sequence with unique hash values and immutable timestamps. Timestamps in transaction block hashes mean that the timing of transactions is transparent and cannot be forged afterward. This enables the facilitates data tracking and the detection of forged information (Kamath 2018). Based on blockchain hashes, each company can check the verification of information and balance in almost real-time.

Second, blockchain's security trust mechanism can provide a valuable complement to some of the shortcomings of IoT technology (Kouhizadeh, Zhu, and Sarkis 2020). Due to the centrality of business today, the lack of security of data collection agencies and traditional IoT devices can easily lead to data loss or manipulation (Pazaitis, Filippi, and Kostakis 2017). Blockchain technology can establish a consensus of trust across the entire network without needing a node to trust other individual nodes, which can solve the key problem of current IoT technology.

Third, since each node has the same rights, the consensus mechanism of blockchain can effectively guarantee fairness (Shin, Kang, and Bae 2020). The consensus mechanism is manifested in the network-wide consensus of transaction verification and confirmation of the current state of the ledger (Wamba et al. 2020). Some blockchain technologies also include programmability by which it can be determined that a transaction should be executed at a particular point in time. These blockchain-based trading rules are known as 'smart contracts' (Caldarelli, Rossignoli, and Zardini 2020), which can reduce transaction costs between companies through the automated execution of pre-set rules and agreement terms.

2.3. Blockchain in the context of supply chain management

In recent years, the importance of technologies has been widely recognised in operations and supply chain management research. In the context of blockchain application, scholars have begun to focus on the interaction between operational decisions and tokenised financing via initial coin offering (ICO). Malinova and Park (2018) propose a variant of the traditional ICO mechanism that can mitigate some forms of entrepreneurial moral hazard. On a related note, several papers have focussed on ICOs for peer-to-peer type platforms. For example, Li (2020) proved that ICOs could act as coordination devices between platform users. Cong, Li, and Wang (2021) consider token pricing and user adoption with intertemporal feedback effects in a dynamic environment. Gan, Tsoukalas, and Netessine (2021) address asset tokenization, more specifically, how the firm should jointly optimise ICO design and firm operational decisions in the face of uncertain customer demand. Here, he also explained the optimal ICO price, token cap, and production strategy using flexible models. Li (2020) establishes a modelling framework that takes channel cost as the decision-making variable of intelligent supply chain technology investment, determines the conditions of technology investment, and discusses the supply chain efficiency and coordination.

At the same time, the rise of blockchain is also changing the process of supply chain production and operation. All parties involved in the supply chain, such as retail warehouses, individual stores, and consumers, can benefit from adopting this approach. Scholars have begun to systematically evaluate the potential impact of blockchain on supply chain activities in different industries. Blockchains are decentralised and trustworthy systems through digital cryptography, information sharing, and consensus algorithms (Crosby, Verma, and Kalyanaraman 2016). All information pieces will update the entire blockchain state and will be observed by all other participants of the supply chain operation. In the food supply chain area, the American retailer Wal-Mart initially used a blockchain to track the supply chain of pork sold in China. The company believes that the information transparency provided by blockchain ensures stricter procurement control and enhance risk management capabilities (Kamath 2018). Meanwhile, Rejeb (2018) proposed a similar concept for Ghanaian tilapia; a white fish often sold illegally. His concept uses mobile technology to input farm-level environmental conditions into the blockchain and then uses RFID tags to track products in the supply chain, allowing consumers to check the source of the products. Zhao et al. (2019) use a systematic literature network analysis method to study the agricultural products' management in the four aspects of traceability, information security, manufacturing, and water source management. In the manufacturing industry, Ko, Lee, and Ryu (2018) studied the application of blockchain technology in composite materials.

Blockchain technology reduces the verification cost by tracing the source of materials and provides an accurate state of composite material quality in the whole supply chain. Kurpjuweit et al. (2021) proposed establishing a blockchain to protect privacy by using symmetric data encryption and achieving a balance between necessary privacy and availability in the automotive supply chain. It is proposed to integrate blockchain technology into cross-company manufacturing processes and solve the problem of low trust between companies in the manufacturing industry through a blockchain internal consensus mechanism and smart contract technology.

To be able to use the full potential of blockchain, the interactions between supply chain partners should be stimulated in a way that they create value equally value for each other (Ghanbari et al. 2017).

2.4. Toe framework

Tornatzky and Fleischer (1990) believed that the process of enterprise's adoption and implementation of technological innovation is mainly affected by three factors: technology, organisation, and environment. The technology environment refers to the adopter's perception of the technology attributes. Organisational background refers to an organisation's internal resources, including the complexity of the enterprise management structure, the human resources, and the management systems. The environmental context refers to the enterprise industry and its interaction with trading partners, regulators, and governments (Lin and Ho 2009). These studies have demonstrated three technical, organisational, and environmental factors, although each specific item of these three factors varies from study to study.

A literature search of the TOE framework shows that the framework has been widely used in the field of information technology innovation, such as for RFID (Lin and Ho 2009), e-procurement (Yeh, Lee, and Pai 2015), and electronic supply chain management (Lin 2014). These studies have demonstrated three factors of technical, organisational, and environmental characteristics, although each specific item of these three factors varies from study to study. For the supply chain management field, the TOE dimension should be supplemented with an inter-firm perspective (Grossmann 2004). This includes intentional partnerships with customers and suppliers of companies (Mathauer and Hofmann 2019). For example, Birkel and Hartmann (2019), from a supply chain ownership perspective, classify technology-, organisation-, and network-related influence factors for IoT technology at the micro-level, while environmental factors at a macro level only influence organisations external to the company (e.g., competitors, decision-makers). Since the potential of blockchain lies in the interaction between supply chain partners as value is mainly created via collaboration, any form of adoption can be seen as an attitude of positive acceptance of new technologies. We adopt the TOE framework as a viable framework for understanding the research challenges of blockchain implementation in the automotive supply chain.

While previous studies have made valuable contributions to understanding how blockchain affects supply chains at a general level, there has been little empirical research on the impact of blockchain technology on automotive supply chains. In particular, the immaturity of blockchain technology and the small number of applications of this technology in supply chain settings mean that, in reality, large-scale adoption cases outside of pilot projects are still lacking, and initial studies based their findings mainly on theoretical discussions. We believe that adding case studies at this stage would be beneficial to the literature, which is why we adopted a collective case study approach to study the application of blockchain technology in German OEMs to address the potential and issues of current automotive supply chain blockchain use cases, such as vehicle digital identity authentication, raw material traceability, sustainability. Our case studies allow us to supplement existing theoretical underpinnings.

3. Methodology

To illustrate and demonstrate how blockchain technology can be implemented in the field of automotive supply chain management, including its potentials and challenges, an exploratory case study (Childe 2011) was conducted. The case study method is widely used to study the application of emerging technologies in supply chain management. This paper adopts the qualitative method of collective case study as we found it as the best fitting technique.

3.1. Research design

We use exploratory case studies to analyse the different applications of blockchain technology in the automotive supply chain to examine the phenomena in enterprise practice. This paper chooses the collective case study method because multiple case studies can help researchers understand the phenomenon in a more comprehensive way, which will enable the proposition of new operational management concepts. Case studies combined with other methods provide an even better understanding of the phenomenon being studied and provide broader access to research data. For each case, an in-depth analysis is needed to understand the essence of the problem, but ultimately all cases need to be analysed as a whole to achieve the full purpose of the entire study (Stak). We summarise how three German OEMs are using blockchain technology to solve difficult problems in supply chain management. In this research area, collective case studies are appropriate and are considered reliable as this approach can both compare similarities and differences (Ramanathan et al. 2017).

3.2. Data collection and analysis

We use the Delphi method to explore the potential and barriers of blockchain adoption in the automotive industry and examine its impact on supply chain management. The Delphi method, developed by Dalkey and Helmer (1963), is used to collect expert-based empirical data and is understood as 'a multi-stage iterative process aimed at transforming opinions into group consensus' (Hasson, Keeney, and McKenna 2000). The consensus-based approach is particularly suited to studying the future evolution and potential impact of new phenomena (Pare et al. 2013). We believe it is highly appropriate to explore the emerging blockchain technologies in the automotive supply chain. In addition, the Delphi method has already been widely used in the operations and supply chain management field, especially in regard to technology adoption (Kache and Seuring 2017).

In terms of sample selection, the study invited three original equipment manufacturers (OEM) operating in Germany, namely Mercedes, Volkswagen, and Bosch, to participate in the interview. Their influence in the industry is strong internationally, and their business priorities are partially aligned but also significantly different in some areas. They were selected for their high level of supply chain involvement and high level of acceptance of innovative technologies. This study mainly focuses on exploration, and the number of cases can be considered sufficient and appropriate to provide a valid basis for this empirical study (Roden et al. 2017). Cross-case techniques were used to analyse and compare interview information (Caniato et al. 2012). Labels and classifications were carried out to compare and identify the similarities of each company. Participating companies are divided into case companies E1, E2, and E3. We limited the interviewees to the blockchain experts of each case company, which are persons in charge of their blockchain factory or act as a technical blockchain consulting expert. Respondents must either be involved in an ongoing blockchain adoption project or conduct research on the topic. They must also have been involved in a blockchain project in the automotive industry for at least 12 months while holding leadership positions in their respective projects. As the scope of this study falls within the scope of their job responsibilities, it is expected that the information collected conforms to the purpose of the study.

To gather information from case enterprises, we developed a semi-structured in-depth interview process with the theme of 'current application scenarios, application potential and difficulties of blockchain technology' to replace the traditional open Delphi round (Jiang, Kleer, and Piller 2017). The approach is considered to be more precise and rigorous, especially when dealing with highly novel phenomena (Edmondson and Mcmanus 2007), such as blockchain. Each interview begins with a brief description of the research and purpose followed by an explanation of the interview process to the interviewee. The average interview time was 67 min. In the second step, based on the potential, barriers, and supply chain impacts identified in the interview, we conducted two Delphi rounds of closed questions to reach a consensus on the importance and power of the potential impacts. Throughout the process of data collection and analysis, we compared identified first-order concepts, summarised similarities and differences by considering the specific interview context, classified and merged, and adjusted terminology to ensure consistency. We then aggregate the identified concepts into secondary topics (Gioia, Corley, and Hamilton 2013). For example, the concepts of monitoring and process improvement build on the secondary subject. We will cover this in more detail in the Results section of this paper.

The collective case study method used in the paper allows us to find novel issues in its context, which lead to meaningful academic findings (Schiele and Krummaker 2011). If we take into account that business operations or processes are partly similar between different industry, our

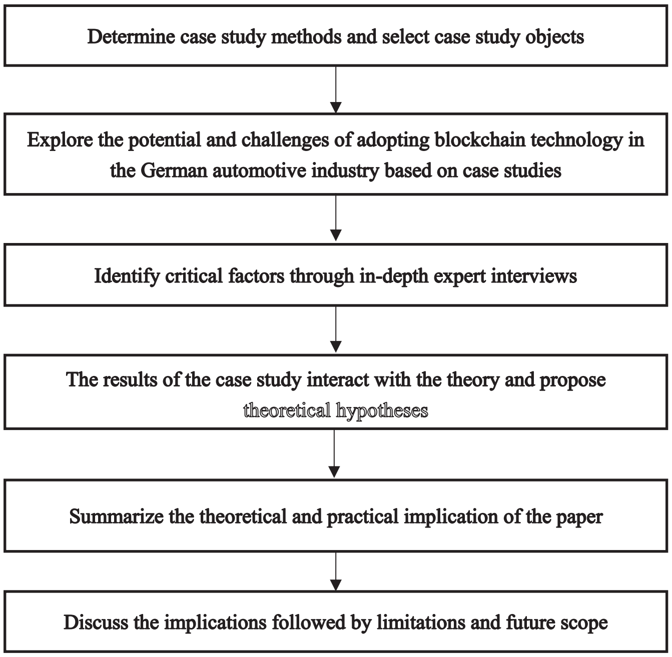

Figure 1. The overall flow of our research work.

research results allow universality to a certain degree and have a wide range of different effects. The overall flow of present research work is shown in Figure 1.

4. Case studies

4.1. Daimler

4.1.1. Company Background

Daimler is one of the largest commercial vehicle manufacturers, the world's largest luxury vehicle manufacturer, and a company with world-leading products and a global supply chain. In 2017, Daimler began to cooperate with technology start-ups to explore new opportunities in the following six fields: artificial intelligence, connectivity, new retail, customer experience, smart logistics, and cutting-edge engineering.

4.1.2. Current applications of blockchain in company

To some degree, a vehicle's identity can be seen as similar to that of a person. The initial birth certificate of the produced vehicle is an important time in the vehicle's entire life cycle. All subsequent information such as vehicle delivery, registration, maintenance, end-of-life mileage of the vehicle will be based on this. When a car is repeatedly traded, the customer's primary concern is the data of vehicle's accident, maintenance and mileage. Daimler has developed a blockchain-based platform that stores all financial and transaction data about the vehicle's life cycle in a Vin (Vehicle Identify Number). Users can track and check the car's entire traffic record through the unique Vin of the car. Even as a third party, it is possible to check the mileage when negotiating with the seller. Vehicle identity sharing and vehicle classification technology are key components of the new mobility ecosystem and as part of the transportation Internet of Things. The construction of a blockchain data platform can help these ecosystems potentially reorganise the automotive and mobile industries, and potentially innovate a whole new business operation model.

Table 1. Barriers for blockchain projects at Daimler.

Barriers	Description
Cooperation between industries	• Immature technical capabilities • Negative blockchain reputation • Technical communication barriers • Uncertainty of investment
Bootstrapping problem	• Uncertainty of the industry outlook • Nobody wants first mover problems
Blockchain system integration barrier	• IT system legacy • High cost of blockchain integration
Digital link barriers	• Lack of digitalisation in suppliers • Less standardised processes at suppliers

4.1.3. Potentials and applications

Daimler provides vehicle digital identity to complete the guarantee of transparency and visibility of vehicle information, so as to meet the increasing demand for vehicle information from customers. Digital Identity can be used to prove vehicles' existence, manage access control, confirm product characteristics and ownership, track vehicle life and other important events, and become a link between the actual vehicle history and a digital copy of the product. Through the traceability characteristics of the blockchain technology, each vehicle has a unique digital identity. Also, the information is associated with a single shared ledger, which is significant different from transactions between stakeholders that are stored in a centralised database. In the digital identity, the data from the digital twin is immutable, and the system only needs to update the digital identity with new entries. In other words, the vehicle's birth certificate is an immutable anchor in a VIN extendable system that generates trust between different participants in an ecosystem. Simultaneously, it is crucial always to determine the exact source of vehicle data because only if authorised person can access data, it can be ensured that transaction fraud is prevented and data quality, efficiency, and accuracy are improved from the source. Based on this, OEMs' recall management process can be optimised through parts tracking data, resulting in the achievement of safer mobility.

4.1.4. Barriers for blockchain projects in companies

Although Daimler has proven that blockchain can achieve data traceability and information transparency along the supply chain, the barriers that are emphasised are shown in Table 1.

The first barrier is the missing cooperation with internal and external partners. Blockchain only fully realised its advantages if it is used in an ecosystem with a higher number of different companies. Due to the novelty and the complexity of the technology, it is difficult to initially explain it to people without a technical background in an easy and consistent way. This always results in much uncertainty and a lack of understanding among internal and external partners. Another point is high uncertainty about the investment return. To realise an ecosystem-based blockchain project, different stakeholders have to make serious investments in this technology. Initial investments in projects using this technology are hard to justify in a business department due to the high uncertainty as a positive return on investment in the short or medium term cannot be guaranteed.

The second one is the bootstrapping problem. Major corporations usually follow the strategy that it is better to be a fast follower than to be a first mover. The reason for this is that being a first mover is always very expensive and difficult because they always make many unknown mistakes. As one senior manager puts it, '*There are always unknown mistakes to be made with new technology, and following quickly can help you learn directly from the mistakes of the pioneers, which is faster and more effective*.' Generally speaking, established companies believe that start-ups should be pioneers in technological innovation, and then they develop their own new products on this basis, improve their technical methods or join forces with them. However, if all companies want to wait and see and nobody wants to be the first mover, there is a big problem because then it comes to a standstill.

The third barrier is the lack of digitalisation in the supply chain sector. While the blockchain's immutability makes it impossible to change existing data, there is still no way to ensure that every information enter into the blockchain is correct. This is especially problematic if physical goods are tracked on a blockchain-enabled supply chain. For every human input it cannot be ensured that all information are completely correct which undermines the trust of the entire blockchain. The impact of incorrect or damaged initial data on the system supported by the blockchain is complex. As one executive puts it, '*There's nothing to stop me from writing crap in the blockchain*.' The basic problem is the lack of digitalisation in the supply chain sector. Blockchain technology can only be logically thought about, understood, and applied if every participant in the supply chain is already digitally connected. In practice, most raw material suppliers in the automotive supply chain are not digitally connected, which makes data tracking impossible for most processes.

Last but not the least, it is difficult and often does not make sense to integrate blockchain into exiting process and software. Because there are many existing processes and software legacy systems in the existing IT system environment. For focal companies, there is almost nothing to be gained by integrating a blockchain system, and it is hard to achieve real efficiency in the core business.

4.2. Volkswagen

4.2.1. Company background

Germany-headquartered Volkswagen Group is an automobile manufacturing company. It is the largest automobile company worldwide and one of the most powerful multinational corporations in the automobile industry. Volkswagen Group has 68 wholly-owned and joint-ventures subsidiaries globally, whose business fields include automobile research and development, production, sales, logistics, service, auto parts, auto rental, financial services, auto insurance, banking, and IT services.

4.2.2. Potentials and applications in company

In the automotive industry, the sustainability of raw materials and the transparency of each product part's raw materials are critical. The use of sustainable raw materials is the basis of the company's social responsibility. Although in Volkswagen's complex global supply chain, many actions have been taken to improve transparency in the early supply chain stage, the raw materials' sustainability and production conditions cannot be guaranteed. To eliminate potential risks in this area, Volkswagen worked with the start-up Minespider to develop a supply chain pilot project for the cobalt sourcing on a blockchain. The project is built on a multi-layer architecture, the first layer contains publicly available information, the other layer consists of private data blocks, which cannot be tampered afterwards, and the third layer is based on an encryption system. In the case of private block, from discontinuous suppliers to secondary suppliers, to the suppliers of commodity extraction or recovery, different supply chains constituted by them all operate in a unified blockchain technology system and they establish a digital infrastructure together for transparent information exchange.

4.2.3. Potentials and applications

Supply chains can be controlled, and automobiles should be produced in ways that protect workers and the environment. As one executive puts it, '*Digitalisation provides important technical tools that allow us to understand more details about the mineral and raw material pathways in a cross-border supply chain, and we use deciphering technology to improve transparency and security of supply chain processes before we engage*.' Different first or second-tier suppliers provide the batteries which are captured on this blockchain, and the whole project covers nearly half of the company's battery demand. Using the blockchain technology in this pilot project enables the company to track raw material information throughout the entire process from the source to the production of cars and recycling.

In addition, the lead pilot project can also expand Volkswagen's cooperation framework. After successful technical operations, Volkswagen has planned to apply the technology to other products and supply chains to ensure its suppliers meet certain required sustainability levels.

4.2.4. Barriers for blockchain in company

A senior manager of Volkswagen believes that the most significant barriers to broader blockchain applications are shown in Table 2.

First, the ambiguity and uncertainty of data legally protection. It is not yet sure whether customer data on the blockchain are also in the future always anonymized. As one executive puts it, '*If there are quantum computers, it is not clear what impact they will have on each blockchain. It has caused the OEM's legal department to worry about the uncertainty of data protection and potential data leakage*'

Table 2. Barriers for blockchain projects at Volkswagen.

Barriers	Description
Legal and regulatory issues	• Privacy of customer data • Data protection and supervision • Rights and responsibilities of large-scale technology applications
Technical standardisation	• Inconsistent data quality standards in the supply chain

(E3).Which is the main reason why blockchain has not been able to establish itself, even though it would have a huge advantage from its usability.

Second, it is hard to achieve standardisation within the industry. Voluntary cooperation between OEMs is historically difficult, and every OEM wants to build its own solution and do not want to work with software from a competitor. This mindset makes standardisation and the required cooperation extremely difficult. Even if every OEM company wants to use its own software, it is required to standardise the interfaces between these systems to still exchange information on a shared blockchain. Using some industry-wide arrangements, standards have to be defined, which define how data is transferred.

4.3. Bosch

4.3.1. Company background

Bosch is a German industrial enterprise, mainly engaged in the automobile and transportation technology, industrial technology, consumer goods and energy, and construction technology industries. Bosch is the world's largest automotive technology supplier, and its business covers gasoline systems, diesel systems, automotive chassis control systems, automotive electronic drives, starters and generators, power tools, household appliances, transmission and control technology, thermal technology and security systems.

4.3.2. Current applications of blockchain in company

In the future, machines will communicate through the network and establish business relationships with each other. Bosch is developing a product prototype that uses blockchain technology to improve the charging process of electric vehicles. This project has left the pilot phase and is currently tested with the goal of soon adoption. The goal of the project is to achieve a personalised payment experience through the application of blockchain. It can select, book, and pay for charging services and payment for different customers based on a variety of factors and realise the automation of car charging services and payment processes. The working principle of the system is that charging facility operators can provide customers with a transparent pricing model by combining the software developed by Bosch for vehicles and a smart charging station management software.

In addition, the service can also take user preferences into account and provide multiple real-time alternatives. It can be said that the entire process from booking to payment transaction is fully automated operated on the blockchain. Compared with projects of other companies that provide electric vehicle charging stations based on a public blockchain, the uniqueness of the Bosch car charging station project is that it simplifies and customises the entire charging process according to customer needs. It gives the customer the flexibility to choose, reserve, and pay for the charging services they need.

4.3.3. Potentials and applications

Bosch believes that, first of all, blockchain technology is a secure and trustworthy network technology that provides a basis for real-world applications. It is a transparent and immutable database that has the ability to provide relevant results. To customise the customer's experience, it will help the machine understand customer needs more accurately and match customer needs through the collaborative operation of sensors and smart contracts. As a senior Bosch said, '*In order to build trust in the digital ecosystem, we need an open platform and an Internet where users have the right to decide for themselves. If the user is "captive", the web platform provider can change its terms of use at will by gaining independence from Internet giants, users will no longer blindly accept these changes*.' Meanwhile, sometimes processes and parts of the supply chain are unnecessarily and in transparent, especially in cross-border transactions. Increased transparency will result in knowing exactly which screw was installed in which vehicle by which supplier.

4.3.4. Barriers for blockchain in company

Bosch was involved in the groundwork research of blockchain right from the very beginning. After starting a majority of different blockchain projects in the last three years, the company believes that technological maturity is the biggest challenge. As Bosch technology executives said, '*Today, it is not clear how a blockchain can be operated or used in a meaningful and simple way*'. With every new technique, there is a lot of half-knowledge at the start. Since there is currently no technically mature one, a lot of fooling around is done with the technology. There are basically many possible fields of application for the technology, but only a few make sense. The whole thing can end up in a lot of nonsense, where there are dubious projects that damage the reputation of the technology.

Second, security also plays a crucial role because many aspects have not yet been sufficiently tested, and therefore it cannot yet be proven that the blockchain is really safe and reliable for all applications. If a blockchain system is implemented in an automotive, it has to work correctly without a doubt.

Another current problem is the necessity of industrial cooperation. The basic concept of blockchain is based on collaboration, and therefore it only scales if everyone works together and cooperates. Where knowledge and understanding permeate, the co-operator see a relatively high willingness to cooperate, but there are still reservations, especially regarding the cost and uncertainty of return on investment. In some cases, however, cooperation is problematic because it did not exist before or in other areas to the extent

Table 3. Barriers for blockchain projects at Bosch.

Barriers	Description
Technological immaturity	• Blockchain technology communication • Lack of technical developers
Technical safety	• Unsystematic technical testing • Hidden dangers of technical procedures
Industrial cooperation	• Uncertainty of investment • Negative blockchain reputation

required. The most significant barriers to broader blockchain applications are shown in Table 3.

4.4. Critical challenges for blockchain in German Automotive Industry

If we summarised the main challenges that companies faced in their blockchain projects, we get a list of ten items. We applied the technology, organisation, environment framework (TOE) to explain the challenges in adopting blockchain technology in the supply chain management of the German automotive industry. According to Tornatzky and Fleischer (1990), the process of adopting and implementing technological innovation is affected by three dimensions: the technological dimension, the organisational dimension, and the environmental dimension. The technical context includes internal technical capabilities and external technical availability and refers to the equipment and processes necessary for internal and external technologies. The environmental context reflects the overall industrial environment, the macroeconomic environment, and the regulatory environment. The influence of economic and social factors on the blockchain application cannot be ignored. According to the content of the interview, the economic factors affecting the blockchain applications in the German automotive supply chain. This is mainly reflected in the uncertainty of commercial project costs and investment returns. Meanwhile, Germany's regulatory uncertainty is one of the most critical social factors. According to the definition of the TOE model, we incorporate economic and social factors into the environmental context. Consistent with the framework, we adopt the three main dimensions to categorise our barriers. Appendix Tables 4 and 5 summarise and cite statements representative of the interviews (see Appendix A for results).

4.4.1. Technological challenges

We identified four sub-topics in the field of technology application, detection, development, and interconnection of information systems: (a) technology maturity, (b) digital systems integration, (c) technology security, and (d) standardisation of blockchain systems. Blockchain technology is still in its infancy, and as always, there will be a lot of unfamiliar knowledge at the beginning for new technology. One of our experts emphasised, '*The biggest challenge is technical maturity. Today it is not clear how a blockchain can be operated or used in a meaningful and simple way*' (E1). Although blockchain is a great technology, the limitations and uncertainty of new technologies make companies reluctant to invest resources in unmatured technology applications. These circumstances slow down the evaluating and implementation process. The result is the slow progress of the application of blockchain technology in the supply chain.

As widely accepted, data in the automotive supply chain is intended to reflect physical information about raw materials, inventories of products, finished goods, and commodity transactions. Although the information on the blockchain is secure and reliable, it is also possible to fake the original data input. To connect the information technology of the blockchain with the physical world, it is necessary to realise the digital system integration at each node which is part of the supply chain. However, many blockchain integrated processes have not yet been fully tested for safety and security, which is why it is hard to prove the security and reliability of a blockchain application.

In addition, timely collection and processing of standardised data at different endpoints is a prerequisite for successful traceability throughout the supply chain. However, the data structure and information flow on the supply chain have not formed a unified standard. The lack of a unified standard will prevent interoperability between supply chain IT systems. As a result, it will lead to the failure of network collaboration and affect the key information capture and operation practice of blockchain technology in the supply chain. As the expert mentioned, *'It's difficult when OEM uses different concepts, and a supplier is between these systems'* (E3). In summary, enterprises need to consider the horizontal technological capabilities of blockchain, including the technology maturity, technology security, digital systems integration, and technology standardisation related to the supply chain.

4.4.2. Organisational challenges

The implementation service of blockchain technology depends on the organisational structure. Next to technical challenges, we further identify adoption barriers of blockchain technology at the organisational level, which mainly include (a) intra-industry cooperation, (b) the bootstrapping problem, and (c) stakeholder recognition. Interviews found that some industry leaders are not interested in blockchain applications because companies and their supply chain partners lack an understanding of the technology, which is a major obstacle to its adoption.

If it comes to new technical solutions, companies believe that fast followers can learn directly from the mistakes of the pioneers. It enables them to quickly and efficiently improve the early-mover product and avoid some mistakes. Established companies see themselves as technology integrators and core architects who are trying to achieve technological leadership through cooperation with start-ups and smaller suppliers. However, such an inactive attitude can easily lead to technological stagnation. As one of our executives said,'*You look at what the successful companies have done wrong and how you can further improve their approaches. However, if all companies wait and see and do not want to be the first mover, there is a big problem, because then it comes to a standstill*' (E2).

Both internal and external stakeholders of the supply chain are important factors in promoting blockchain applications. Established companies need to realise that they can facilitate the implementation of blockchain technology by properly utilising the resources and knowledge development of supply chain partners. The company may also need to take a leadership role in bringing supply chain partners together. Also, it is necessary to learn from existing blockchain initiatives, as any initiative will fail if a high number of the supply chain are unwilling or able to participate.

4.4.3. Environmental challenges

Environmental factors will also have an impact on the adoption of new technologies across the industry. Through the interview, it is found that (a) governance conditions such as laws and regulations (b) the general investment environment and other factors restrict the development of blockchain technology in the German automotive supply chain.

Interviews with OEMs executives revealed that 'uncertainty about legal regulation' is the biggest barrier to companies adopting blockchain technology. Blockchain projects need to comply with local laws and regulations and comply with relevant data governance guidelines. However, from a legal point of view, the regulatory agencies' position regarding blockchain projects is not clear in terms of data privacy. Currently, there are no laws that officially regulate data security, privacy review, and other activities touched by blockchain technology. As one expert pointed out, '*Sometimes, a libertarian peer-to-peer crypto-anarchist community is not compatible with conservative, tax-paying* industries and companies' (E2).

In terms of the investment environment, negative news about blockchains, such as black market or illegal business practices, may lead to investors' boycott of project investment. Second, commercial projects cannot promise a positive return on investments in the short or medium term, causing investors to worry about the uncertainty of cost and return on investment. These two are obligations also barriers preventing the scale-up of blockchain projects. Figure 2 presents the critical challenges for blockchain in the German automotive industry.

4.5. The impact of blockchain on the German automotive supply chain

According to the supply chain effect we put forward in the qualitative interview, the supply chain using blockchain technology may reshape the value creation process. The TOE framework can help us to deeply understand the impact of blockchain technology on the German automotive supply chain. The technological advantages of blockchain in the automotive industry can lead to the fact that blockchain technology increases the visibility of the supply chain, mainly driven by traceability of raw material information and transparency of transaction information specifically, as some of the processes in the supply chain today are very complex and opaque. Many upstream suppliers' processes are still relying on handwritten paper documents, which impedes the efficient flow of goods and information. Blockchain technology allows the creation of digital records of information related to production, transportation, and transactions. Access control mechanisms ensure that stakeholders on the blockchain can only assess their related products' entire life cycle information. Blockchain technology provides reliable proof of the life cycle information, which is an important unique advantage.

Taking into account organisational factors, the impact of blockchain on the inbound and outbound supply chains depends largely on how the technology meets the needs of stakeholders. Supply chain transactions are blockchain-based and will be validated through consensus among all supply chain partners and other relevant bodies such as communities, governments, and industry associations. In addition, digital processing generated by the application of blockchain technology in the automotive supply chain (Bai and Sarkis 2020) will gradually automate all aspects of the supply chain without manual operations, thus reducing complexity and saving costs. Another benefit is that the process improvements brought about by blockchain technology will also affect quality management. Blockchain technology can accurately define a product's current production process steps, its location in the supply chain, and all suppliers involved, enabling it to reduce waste and improve operational performance.

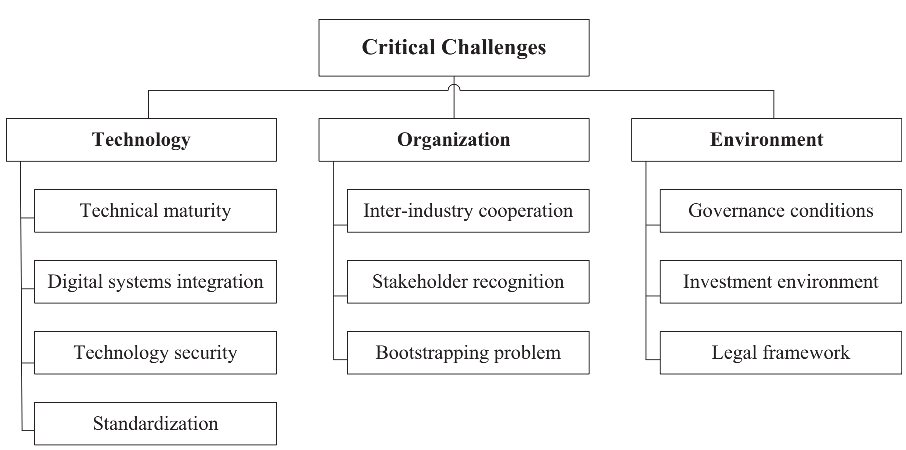

Figure 2. Critical challenges as inferred from interviews.

Finally, experts stress that blockchain is particularly effective in new business models. Blockchain alters the traditional division of labour among supply chain participants and opens up new possibilities for value creation in terms of scalability, flexibility, and transparency. Our interviews suggest that because all parties must be accountable for the information on the blockchain, OEMs can build new customer-centric business models that are not currently possible by deeply engaging customers in the product manufacturing process and providing information and some level of customisation.

In summary, our case study shows that the adoption of blockchain technology in the automotive industry will impact three main aspects of the supply chain, namely supply chain transparency, supply chain efficiency, and the emerging of a new business model. Based on our interview data, we propose:

> Proposition 1a: Integration of blockchain technology in the automotive industry will increase supply chain transparency.

> Proposition 1b: Integration of blockchain technology in the automotive industry will improve the efficiency of supply chain operations.

> Proposition 1c: Blockchain in the automotive industry will enable new value creation on the supply chain, resulting in the emerging of new business models.

5. Discussion and conclusions

5.1. Conclusion

In essence, modern supply chains are complex, geographically dispersed and multi-echelon supply networks, and diversified regulatory measures increase the risk of supply chain management sharply (Lambert and Enz 2017). Information asymmetry, unreliable product sources, fraudulent behaviours, etc. hinder the continued stability of supply chain transactions. Related research has shown that data integration technology has obvious advantages in delivering information and realising supply chain information sharing. With the development of information technology, several technologies have been applied to product tracking in the supply chain. Blockchain technology, as a public digital platform connecting various participants in the supply chain, has advantages in realising real-time and transparent information, reducing enterprise costs (Abeyratne and Monfared 2016), improving product quality and other aspects. It is attractive in many industries including manufacturing. We have conducted in-depth research on three major German original equipment manufacturers, aiming to contribute to the research on the application of blockchain technology from both theoretical and practical aspects.

5.2. Theory implications

Our paper adds to the discussion on the integration of digital technology towards supply chain management. The results cleary show that blockchain technology can create a new information-based operation model in the future.

Our first significant research contribution was that we proposed an overall framework for the impact of blockchain technology in the German automotive supply chain by evaluating supply chain management, quality control, information testing, and a comprehensive assessment of German OEMs. Blockchain technology has laid a foundation for the sustainable development of the automotive supply chain in the aspects of raw material traceability, information monitoring, immutability, and cost-saving. In addition, this article is based on case studies and available literature. Here, blockchain technology is put forward to break the traditional division of the supply chain. From the perspective of extensibility, degrees of freedom, redesign of automotive supply chain visibility, operational efficiency, and new business model, blockchain provides a new value creation based on automotive supply chain theories, which is a basis for further empirical research.

The second important contribution is that our paper further develops the interaction between blockchain technology and organisations based on the TOE framework. In terms of the critical challenges in the application of blockchain technology, we offer different explanations. It should be mentioned that the previous obstacles to the application of blockchain technology were mostly technical challenges (Yadav and Singh 2020), but in our case study, we found that the cooperation of internal and external partners, technical guidance, shortage of human resources, legislative regulation and many other organisational and environmental barriers also play an important role. Therefore, we respond to Kurpjuweit et al. (2021)'s call to manage technical issues in knowledge exchange between organisations and use the case study approach in this paper to validate these challenges and extend new key influencing factors.

In addition, this paper verifies that the key success factors of blockchain technology implementation proposed by Hastig and Sodhi (2020) are the company's technical capability, willingness to cooperate, technology maturity, and leadership. We further contribute to the literature by identifying specific key variables that influence the adoption of blockchain technology.

5.3. Practical implications

Using the Delphi method, we provide a range of integrated application possibilities. We summarise the application challenges of blockchain technology in the German automotive supply chain development through the TOE framework. The results of our study can serve as a reference for practitioners to integrate blockchain technology in the automotive supply chain.

First, at the technical level, there are various obstacles such as differences based on processes and IT systems, the lack of uniform standards in the industry, immaturity of the technology, but it is now evident that blockchain can be incorporated into the internal organisational structure of companies through system integration. Therefore, we suggest that before promoting blockchain technology, managers should first simplify their own information system environment mainly internally at the technical level to reduce the compatibility of their own Information systems. And at the same time, it is necessary to develop a unified industry standard, which is the premise of the successful implementation of blockchain technology.

Secondly, from an organisational perspective, participants should form an internal team with rich resources and highly technical development ability to be able to quickly solve technical problems at the organisational level. At the same time, success can only be achieved if all supply chain participants participate in an integrated blockchain ecosystem. As a result, core enterprises need to shift their thinking towards collaboration and open sharing approach and thereby to facilitate collaboration between internal and external partners. This can also be achieved by creating internal incentives for supply chain partners or educating other stakeholders (e.g., their suppliers) about the benefits of participating in blockchain applications.

Finally, at the environmental level, managers need to establish a global perspective and focus on building trust between the enterprise itself and supply chain participants, which will help establish benefit-sharing and risk-sharing mechanisms before evaluating blockchain technology projects to achieve effective governance of the supply chain. These factors, in turn, influence the willingness and likelihood of enterprises to participate in the application of blockchain technology in the supply chain.

5.4. Limitations and future work

Although our research provides some indications of optimistic prospects for the practical application of blockchain technology, we have found various obstacles that need to be solved on a technical, organisational, and environmental level. Automotive managers believe that before most of these problems are not solved, the impact of blockchain-based systems in the supply chain will be limited. We encourage companies to share application results from their pilot projects more openly so that academic research can explore more specific impact dimensions in future studies, such as blockchain technology's impact on supply chain performance. These findings can positively impact the overall industry in this area, as the results could be applied to other cases.

We will conduct a longitudinal study on a mature blockchain-based supply chain in a specific industry in future work. This study will deeply analyse the benefits and challenges for each stakeholder in the supply chain throughout the entire development and integration process. Finally, based on a larger data set, we expect that future work will verify or challenge the theories that we have obtained this time through empirical research to advance research in this area and increase its relevance to reality.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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Appendix A

Appendix Table 4. Results of expert interviews on "potentials".

Category	Potentials	Representative quotes
Monitoring	• Transparency; • Traceability; • Trust; • Digital Identity; • Tokenization;	"Already now there are several pilot projects that show that the blockchain will play an important role in the supply chain by increasing trust and security while reducing costs." (E1) "Today there are sometimes processes and supply chains that are unnecessarily long and untransparent. "This is especially the case with cross-border transactions and processes." (E1) "Blockchain will be able to define exactly where the shortcomings in the projects in production and the supply chain lie. Increased transparency will result in knowing exactly which screw was installed in which vehicle by which supplier." (E1) "On the other hand, blockchain can also lead to trust, because you can see exactly who is giving whom further data, These security aspects and the complete traceability are decisive advantages in the IoT context." (E1) "With smart VIN, Daimler has developed a blockchain-based platform that stores all financial and transaction data of the vehicle's life cycle. It would store data such as delivery, registration, maintenance and mileage." (E2) "But in a regulated environment. Tokenization via regulated exchanges. And with this I finance the necessary infrastructure. At least that would be a scenario that is being discussed in the industry and is certainly possible." (E2) "Essentially, these are the monitoring of materials such as cobalt from African mines and the use of child labour. There it is already live and the only case where it was implemented." (E3)
Process Improvement	• Quality Management; • Process Reengineering; • Quality in Production;	"I can imagine that it can lead to an increase in efficiency on the one hand and on the other hand to completely new features and business models." (E1) "The Mobility Blockchain Platform (MBP) has the following features: Self-service, this means that you can use the service yourself and independently." (E2) "Today, as an OEM, you have existing suppliers that are always the same. It is very difficult to add new ones because the trust is not there or the processes are not there. Here it makes sense to think about a blockchain solution." (E3) "The proof can be made by the blockchain and thus increase the quality in production. In this case, the sequence of the components must be controlled in production to make it work." (E3)
Cost Saving	Support the Digitalisation;	"Already now there are several pilot projects that show that the blockchain will play an important role in the supply chain by increasing trust and security while reducing costs." (E1) "Here there is currently still too much manual processing with paper. Therefore Blockchain could strongly support the digitalisation in the supply chain." (E1) "SIM system became popular because everyone can talk to each other and still everyone has their own customers. This must exist for blockchain, where the blockchain enables communication between internal company systems, the blockchain will make it very cost effective." (E3)
New Business Models	Scalability;	"Blockchain is particularly effective for new business models when you start out on a greenfield site. Then you can do things that are unique in terms of scalability, degrees of freedom and possibilities." (E2) "The combination of IoT and Blockchain is also being worked on very hard. Data has a value and if I provide it to someone, I can pay for it. An example would be that if my car notices that a road is slippery, it sends the information about other cars in the area and they pay me 1 cent for this service." (E3)

Appendix Table 5. Results of expert interviews on "barriers".

Category	Barriers	Representative quotes
Technology	• Technical Maturity; • Security of All Applications; • Integrate System; • Digitally Connected; • Standardisation;	"The biggest challenge is the technical maturity. Today it is not clear how a blockchain can be operated or used in a meaningful and simple way." (E1) "Also the topic of security plays a very important role, because many aspects that have not yet been tested and therefore it cannot yet be sufficiently proven that the blockchain is really safe and reliable for all applications." (E1) "It is very difficult and often does not make sense to integrate blockchain into existing system landscapes, where there are already many legacy systems with existing processes and software." (E2) "Large parts of the supply chain of raw material suppliers are not digitally connected. Especially in countries outside Europe and America, there is the problem that there are less standardised processes, which are often not traceable and digital." (E2) "Everyone wants to build something of their own. That makes it all the more important to achieve standardisation, where everyone can make their own concept, but can communicate with others and others can use it. That is the main reason why MOBI exists." (E3)
Organisational	• Industrial Cooperation; • Capable Developers; • Cooperation Among Internal and External Partners, • Bootstrapping Problem;	"In some cases, however, cooperation is difficult because it did not exist before or in other areas to the extent required." (E1) "It should still take 2-3 years. The reason is that you have to rely on partners and conduct reconnaissance. " (E1) "We actively participate in GAIA-X or go to events of the federal government because there you can meet all industry players. You need such large rounds to discuss these topics at a table on management level and talk about cooperation." (E1) "However, we still need the cooperation of start-ups and other industry companies, because this is the only way to realise different proof of concepts. Start-ups can set new technical impulses from outside." (E1) "Blockchain is a fascinating technology, but it is difficult to grasp and understand. It takes a relatively long time to build up a basic and deeper understanding among different partners." (E2) "Major corporations like OEMs usually have a strategy that it is better to be a fast follower than a first mover … … However, if all companies wait and see and do not want to be the first mover, there is a big problem, because then it comes to a standstill. "(E2) "There is an acceptance problem, because the entire technology is perceived as rather mixed. There is currently still a lot of scepticism." (E2) "The problem with Blockchain is that it only makes sense when as many people as possible work together, when everyone does things on their own, like the Volkswagen Blockchain -> stupid idea." (E3)
Environmental	• Negative Press; • Marketability and Return on Investment; • Non-democratic Environment; • Regulation in Germany; • Legal Department	"The ignorance of most people and companies leads to the fact that many blockchain equate with digital payment and tokenization of company shares. This tokenization of company shares was more of a scam and a fail for the whole blockchain movement. (E1) "The technology also has certain problems and risks: for example, it could be problematic if the blockchain is used in a non-democratic environment, as it is totally transparent and traceable." (E1) "In the press however, negative topics are more likely to be discussed, such as dark net markets etc." (E1) "Sometimes Blockchain is also connected to very negative topics in people's minds such as scams, ICOs, Bitcoin, drug dealing, endless energy consumption and waste of natural resources." (E2) "There are still reservations, especially regarding the cost and uncertainty of return on investment. It is difficult to estimate the marketability and return on investment of such projects. Other partners, who are not so good at assessing the technology, have more reservations." (E1) "Another point is that the uncertainty in investment is still very high and therefore larger investments are difficult to justify in tough economic times. Business cases are sometimes difficult to justify, because you cannot promise a positive return on investment in the short or medium term." (E2) "Many blockchain start-ups try to dispute different industries and often have a high level of legal uncertainty, because it is unclear how far data privacy is covered from a legal perspective." (E2) "Potentially, current institutions and regulators feel threatened because there is sometimes less leverage and influence possible." (E2) "The OEM would be responsible for the mileage and thus make itself potentially vulnerable. The legal department doesn't want that, although it would have many advantages for the consumer market." (E3)