Blockchain Technology in Supply Chain Management – A Discussion of Current and Future Research Topics

Tan Gürpinar[1](✉), Nick Große[1], Max Schwarzer[2], Eugen Burov[3], Roman Stammes[4], Philipp Asterios Ioannidis[1], Larissa Krämer[5], Rico Ahlbäumer[5], and Michael Henke[1]

[1] TU Dortmund University, Leonhard-Euler-Str. 5, 44227 Dortmund, Germany
{tan.guerpinar,nick.grosse}@tu-dortmund.de
[2] Dachser SE, Thomas-Dachser-Str. 2, 87439 Kempten, Germany
[3] Fraunhofer IML, Joseph-von-Fraunhofer-Straße 2-4, 44227 Dortmund, Germany
[4] Brutana-Metrona Group, Max-Planck-Str. 2, 50354 Hürth, Germany
[5] TU Dortmund University, Joseph-von-Fraunhofer-Str. 2-4, 44227 Dortmund, Germany

Abstract. Purpose: Today's supply chain management faces complex and globally distributed networks of customers and suppliers. Blockchain solutions serve as underlying IT infrastructures to connect the network participants and enable multiple applications. This paper aims at bringing together and discussing current and future research topics in the field of blockchain in supply chain management. Methodology: In the paper, seven central research topics of the field - strategic realignment of enterprises, governance and profitability considerations, as well as blockchain-based pay-per-use models, additive manufacturing, decentralized markets and cyber-physical production systems - are presented with a state of the art and a research discussion to stimulate prospective blockchain research. Findings: As an outcome, the research topics are consolidated in a research framework and categorized in strategic or application oriented approaches, as well as assigned to blockchain scientific layers.

Keywords: Blockchain technology · Supply chain management · Distributed ledger technology · Field review · Research agenda

1 Introduction

With the increase in digitalization and globalization enterprises around the world have to rethink the way they deal with challenges along their supply chains. Especially enforced by recent crises, e.g. global pandemics, supply chains need to be kept resilient and sustainable, while complexity increases with the amount of stakeholders involved. In times of competitive ramp-up management, there is also an urgent need for concepts proposing transparency and visibility throughout the supply chains [1, 2]. Against that backdrop, IT infrastructures such as distributed ledger technologies (DLT), and especially blockchain

S. Paiva et al. (Eds.): SmartCity360° 2021, LNICST 442, pp. 482–503, 2022.
https://doi.org/10.1007/978-3-031-06371-8_32

technologies, are getting more attention due to their inherent characteristics and functionalities to address the stated challenges while reducing information asymmetries [3]. Throughout this article we are using the prominent term of blockchain technology but imply and cover also the use of other DLT [4]. The term blockchain hereby is described as a "distributed database that is practically immutable by being maintained by a decentralized P2P network using a consensus mechanism, cryptography and back-referencing blocks to order and validate transactions" [5].

Even though there are multiple successful industry blockchain projects and initiatives that combine research and application like e.g. Blockchain Europe, current analyses show that efforts to implement blockchains along supply chains often remain at an early stage [2, 6] and enterprises struggle in successfully completing implementation projects [7–9]. To bring blockchain projects one step further, the strategic realignment of companies (Setc. 2.1) needs to be examined considering concepts to utilize decentralized business models. It also has to be clarified to what extent, business models need to be transformed in order to adopt new cooperation and coopetition concepts. Additionally, there is a research need on how to design effective governance mechanisms for blockchain based ecosystems to enable confidence in cooperation and to ensure long-term business success (Sect. 3.1). Enterprise blockchain applications are often used within inter-organizational settings and therefore they do not only require an increased governance effort, but also profitability analyses become more complex and research is needed to quantify the occurring network effects (Sect. 3.2). Subsequently, research questions about the potential of blockchain for building trust and achieving consensus in accounting models can be addressed (Sect. 4.1), and in-depth transferred to different application areas like blockchain-based additive manufacturing platforms (Sect. 4.2). Finally, investigations are needed on the use of blockchain in decentralized markets (Sect. 5.1), especially if both machines and humans, are interacting in such ecosystems (Sect. 5.2).

This paper reveals a state of the art overview and research discussion of the stated research topics as well as future research needs. Finally a research framework is presented to consolidate the findings and invite researchers to participate in advancing blockchain and supply chain management research.

2 Field Review

2.1 Scope and Overview

In each chapter of the following field review, first strategic topics that enable the use of blockchain in supply chain management are discussed. Then, more application oriented topics follow up that are characterized by the respective blockchain implementation (Fig. 1).

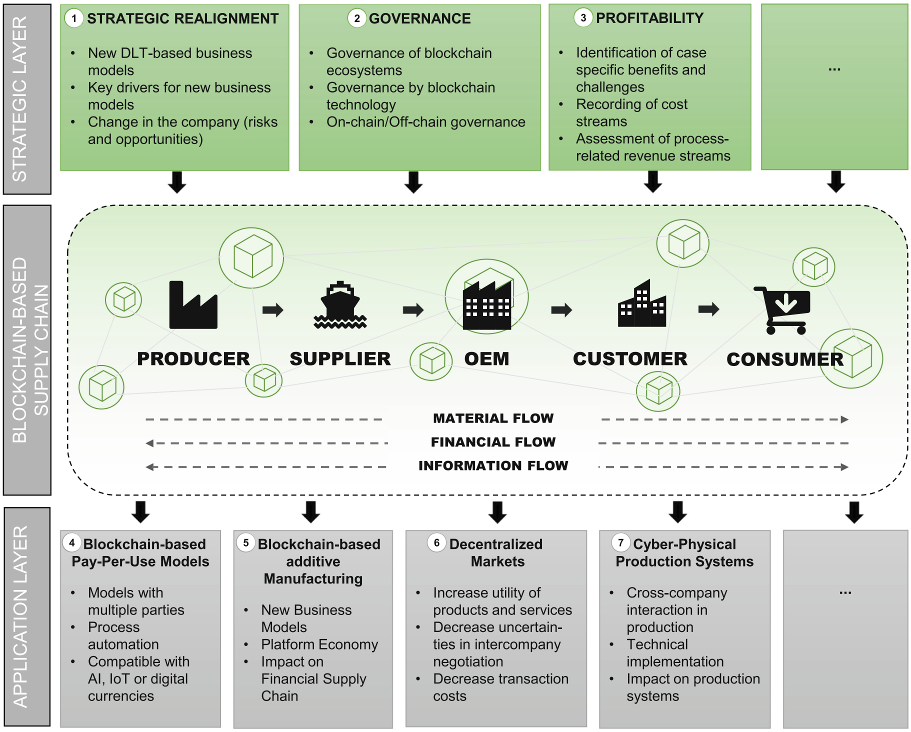

Fig. 1. Research map for blockchain technology in supply chain management

3 Strategic Realignment of Enterprises Through Blockchain

3.1 State of the Art

Academic literature describes constant changes in organizations due to new technology solutions, however, blockchain itself is still a very young field of research. Most distributed ledger technology-based studies are related to blockchain in combination with supply chain management, cryptocurrencies, identities, process architectures, tokenization, energy market, finance, and smart contracts. The combination of blockchain and strategic reorientation of companies has been an underrepresented publication topic so far. A literature review by Klinger and Bodendorf reveals that starting points can be found just on a theoretical foundation with the described topic, but business processes that lead to a strategic realignment through blockchain have not been dealt with more a more practical approach [10]. Current examples of blockchain solutions, development goals for sustainability and new business models are analyzed by [11]. The synergies between blockchain as well as other disruptive technologies are analyzed by Herian, who elaborates on the principle of trust through blockchain technology. Herian explains the change on a strategic shift from the secure assignment of digital property and the associated of new business models [12]. In a systematic literature review, Casino et al. describe the current state of research on blockchain-enabled applications in various fields, such as supply chain, business, healthcare, IoT, privacy, and data management. Trends and emerging research areas are also described, a research gap for strategic reorientation of companies remains open and needs to be investigated [13]. For this reason, it is of interest to investigate the following groups of topics as a research topic: "strategic management, economic theories for blockchain, change management, digital transformation and business models" [14].

3.2 Research Discussion

In view of the growing trend of digitalization, the technical innovation of blockchain is becoming increasingly important. Therefore, the existing research gap with regard to the strategic reorientation of companies is to be closed. It is important to examine what the most important drivers for the strategic realignment through blockchain in the company will be. Furthermore, it is also important to find out what the opportunities and risks of the introduction of new business processes through blockchain will be for the companies. There are a number of research questions that still need to be answered in this area. First of all, it is necessary to clarify what the most important drivers are for the strategic realignment through blockchain in the company. Furthermore, it is necessary to find out what needs in a company require to be changed in order to take advantage of the opportunities offered by blockchain and where the risks lie. Moreover, it is important to clarify how the emerging blockchain technologies can be organized in a way that makes sense for a company and what impact this will have on new business models. Also, the significance of the strategic realignment in the company through the blockchain and what results can be expected are still open questions that need to be clarified.

By closing the research gap of strategic realignment of companies, there are further research gaps that can be investigated. However, the results of the research gaps must be continuously reviewed, as the emerging technologies and thus the market are constantly evolving. It is important to constantly monitor future changes in the framework conditions, technological progress and new scientific findings. Firstly, it is important to find out the most efficient ways to implement blockchain in the enterprises and secondly how the realignment should be implemented in the company. In this way, companies can assess not only the strategic but also the monetary impact when deciding to introduce blockchain solutions. This provides a basis for decision-making with regard to the company's own future design for the use of blockchain.

4 Governance for Enterprise Blockchain Applications

4.1 State of the Art

A few years before blockchain became a subject of discussion, a series of research projects from Weill et al. revealed that a proper (IT-) governance design with a clear assignment of respective roles, decision rights and accountability is indispensable to ensure long-term business success [15]. Enterprise blockchain applications are usually applied to inter-organizational settings, where multiple and diverse participants interact with each other. It becomes apparent that defining a governance model for a distributed cross-organization approach is not as easy as it is for a system managed by a single entity, not least due to several specialties the technology comes along with. A survey from 2019 on global companies in the transportation and logistics industry by the management consulting group 'Boston Consulting Group (BCG)' confirms governance to be a key factor for a successful creation of collaborative blockchain ecosystems [16]. When trying to find suitable recommendations for practitioners and researchers, it might help to first have a look at platform literature. Although this type of literature does not explicitly examine governance questions from the perspective of a blockchain platform or ecosystem, lessons learned are interesting for blockchain governance models, as well [17]. Parker and Van Alstyne, for instance, developed a sequential innovation model to provide practitioners with guidance on the decision about the openness of a platform [18]. They address strategical questions related to the orchestration of external parties from a platform providers' point of view. However, since there are various new features, components and roles that blockchain technologies are endowed with (e.g., on-chain governance mechanisms, token, validators and forks), it is clear that 'classical' platform literature has several shortcomings with regard to the question of blockchain governance.

A second possibility is to seek advice from literature on governance at the protocol level for public permissionless systems, such as Ethereum and Bitcoin. Gasser et al. describe the process by which Bitcoin revised its core code to implement' multi-signature transactions' [19]. Using forum posts as primary data, Andersen and Bogusz develop a framework for assessing the potential consequences of specific forking events [20]. By referring to past Bitcoin forks and the social contexts influencing these forks, their framework tries to help practitioners with the question around what to consider when developing a governance model for blockchain infrastructures. Of course, public permissionless systems clearly differ to private or public permissioned systems designed for consortial / enterprise applications, when it comes to anonymity of participants and legal or jurisdictional questions. Same applies to hybrid approaches, a combination of both, where public permissionless systems can be used for anchoring purposes, meaning that hash values are being stored periodically on these systems for verifiability reasons [21].

4.2 Research Discussion

This indicates a research gap for the design of governance models for enterprise blockchain applications, as researchers focus on non-blockchain platform governance or governance related to cryptocurrencies, such as Bitcoin or Ethereum, so far. Additionally, several industry or politically funded projects highlight the importance to extend academic research to governance of enterprise blockchain applications and networks. The German Federal Ministry for Economic Affairs and Energy, for instance, explicitly states research and development of effective governance structures for using distributed ledger technologies in the logistics sector within their 'Blockchain Strategy' paper [22]. Beck et al. propose an extensive research agenda on blockchain governance, as well [23]. Regardless of the various possible blockchain architectures (private permissioned, hybrid, etc.) for enterprise blockchain applications, it is of interest which components have to be considered for the setup of a respective governance models and how a systematic approach could look like. Conversely, it is of interest how governance models from already existing enterprise blockchain applications can be assessed. Considering a situation where an organization has to evaluate whether a blockchain solution initiated by another industry player meets the own strategic needs (i.e. when it comes to the question whether to join an already existing initiative), the evaluation of the respective governance model could reflect an assessment from a strategic point of view.

Another interesting field of research is the interplay of the two fields governance ‘by’ blockchain and governance ‘of’ blockchain. In contrast to the latter, which has been described above, governance by blockchain investigates how blockchain technologies can help to simplify governance referring to the process of governing eventual principal agent problems between investors or share-holders and managers, for instance. Yermack evaluates how blockchain could improve corporate governance decision making processes by providing greater transparency [24]. Pelizza and Kuhlmann argue that blockchain cannot only be seen as information infrastructure that has to be governed (’governance of blockchain’), but also offer the possibility to function as governance actor (’governance by blockchain’), providing a basis for algorithmic decision making [25]. Hence, governance by blockchain tries to identify fields of applications where the technology itself is supposed to help enforcing rules, e.g. voting rights, value distribution, but also simplifying traceability of decision paths on a corporate level [26]. Respective research on the interplay of ‘governance by blockchain’ and ‘governance of blockchain’ could investigate to what extend smart contracts can be used for verification purposes regarding the question whether the involved parties adhere to previously defined governance rules.

5 Profitability of Enterprise Blockchain Solutions

5.1 State of the Art

In literature explicitly on blockchain and distributed ledger technologies guidelines can be found that have been developed to decide whether the technology is a good fit for intended use cases. Recently, these guidelines were developed further and extended to more comprehensive process models that cover benefits and challenges. Nevertheless, concrete monetary factors or any further profitability considerations are not included in most approaches [8, 27, 28]. Exceptions are made e.g. by [29] who analyze the benefit factors of blockchain solutions more precise and develop predicted scenarios for the future. In contrast to that, literature dealing with the evaluation of information systems already developed concrete methods and models for profitability analysis. Mainly, the approaches utilize static or dynamic evaluation procedures [30]. Particularly among the dynamic procedures are methods such as the utility analysis that takes qualitative, multidimensional factors into account, which are of relevance when it comes to the evaluation of systems that generate intangible benefits [31]. Even though these methods can be transferred to the blockchain research field, blockchain solutions vary significantly from traditional information systems and therefore certain criteria remain unconsidered.

In the literature field of innovation management and emerging technologies, a number of new approaches exist that provide suggestions to consider profitability. The scholars identify concrete criteria to be evaluated with regard to potential economic evaluations and develop checklists that serve as a first evaluation step [32]. In addition to that, recent approaches utilize methods like the interpretive structural modeling (ISM) to concretize the benefit factors of nascent technologies, like cloud computing or artificial intelligence [33–35].

On the one hand, the state of the art shows that there are no approaches yet to evaluate the profitability of blockchain or distributed ledger technologies. On the other hand, it becomes clear that other research fields do provide methods and models for other objects of investigation that might have the potential to be transferred and analyzed regarding their utilization for the blockchain field.

5.2 Research Discussion

The stated research gap is also supported by various authors. As early as 2014, Platzer pointed out that there is a need for economic investigations of emerging technologies [36]. Following up Platzer, Kesten et al. point out that the factors influencing economic value are often not known to or determined by the practice. As a result, the influencing factors that are critical to the success of an investment are often not taken into account [37]. Klischewski tranfers the problem situation to the topic of blockchain technology in 2018 and points out that the financial benefits and actual costs for companies are a relevant research gap [38]. Andrian follows up on that statement and relates it in particular to the use of blockchain technology in a corporate context. As an example, he refers to a lack of readiness to use the technology unless corporates elaborate the benefits more concretely [39]. Queiroz et al. and Cole et al. also explain that the potential of blockchain technology still needs to be explored in more detail - respectively, that there is a lack of studies on the topic so far [40, 41]. Last but not least, Mika and Goudz point out that a holistic economic assessment of the technology should be made possible in order to scale blockchain implementations [42].

Based on the previously described research gaps, the need of a blockchain-specific model for profitability evaluation emerges. To develop such a model, it can be necessary to first understand what opportunities and challenges arise from the use of blockchain technology when used in enterprises and particularly in enterprise networks. Based on those outcomes more concrete cost and benefit factors can be derived and associated to business processes. If the factors are measurable, as a next step the type of the evaluation situation and types of factors influencing profitability can be analyzed in more detail. This way, the exact requirements of evaluating blockchain solutions in enterprise networks can be derived and compared to existing methods for profitability evaluation. Finally, the design of a particular profitability evaluation model can be determined and validated to ensure it meets all requirements.

6 Blockchain-Based Pay-Per-Use Models

6.1 State of the Art

With the rise of blockchain technology, a variety of new business models emerged. However, the technology also has the potential to reengineer existing processes and models and to expand their functionality and usability [43]. Blockchain-based pay-per-use models are one example. In contrast to the traditional purchase of products or services, pay-per-use is a usage-based pricing model, since products are no longer purchased but are billed according to their respective use, so that neither acquisition costs nor capital commitment are incurred [44]. Manufacturers might no longer act as sellers but rather as service providers. General Electric or Rolls Royce, for example, offer airlines the use of their engines according to operating hours. As a result, their customers pay only for the service they use, the necessary engine thrust, rather than for the product itself [45].

For a successful and sustainable implementation of pay-per-use models, consensus on the consumption data is of decisive importance. In the case of aircraft engines, as explained above, it still seems possible to consult a trustworthy data basis, for example on international flight schedules. In the case of a production machine, such as a 3D printer, which is located on the customer's premises and is also operated by the customer, this is a far greater challenge. Information asymmetries naturally arise, especially on the sales side, and the parties involved must trust the integrity of the available consumption data. While such factors may represent a manageable risk for direct customer-supplier relationships, the degree of complexity increases as corporate networks increase in size. If, for example, additional suppliers, insurance companies or financial service providers are also present in the system, the requirements for data integrity increase. By using connected sensors and measurement tools, and thus IoT devices, trustworthy and transparent data can already be collected in the first step. However, in order to be able to store and use this data in a tamper-proof and traceable manner, the use of blockchain technology is an advisable option.

Recent efforts from industry and practice show the interest in combining blockchain technology and the pricing model of usage-based systems. A prominent example from the financial sector is the "CR Pay per Use" project of the German Commerzbank, which is one of the first major banks to offer a digital, usage-based leasing product, which records and transmits the usage intensity of the object on site via a machine-to-machine (M2M) gateway [46]. Thereby, blockchain is being considered as a trusted data foundation between the bank and the customer [47]. In addition to developments from the financial sector, companies from the manufacturing sector also offer direct usage-based pay-per-use solutions, for example machine manufacturer J.G. Weisser Söhne GmbH & Co, Gebr. Heller Maschinenfabrik GmbH and C-parts specialist Würth Industrie Service GmbH & Co. KG. While existing solutions take advantage of the benefits in terms of increased connectivity through IoT-devices, they do not explore the benefits of integrating blockchain technology. Comparably, the scientific literature is currently investigating the use of IoT devices in usage-based pricing models and addresses the potentials of corresponding business models, the way they can be mapped and how such pricing models can be introduced [48, 49]. However, the benefits of blockchain in such models has not been scientifically studied. Besides initial considerations, such as the representation of pay-per-use models with the support of Blockchain-based smart contracts [50], the topic still needs to be researched further.

6.2 Research Discussion

The characteristics of blockchain generate trust and transparency while ensuring the integrity and tamper-resistance of consumption data. This demonstrates the technology's utility for pay-per-use models. Especially in systems where multiple parties interact, for example along national and especially international supply chains, the integration of blockchain for the realization of pay-per-use models appears reasonable. Blockchain has the potential to address restrictions and problems of pay-per-use models, for example on data confidentiality or tamper-proof traceability of transactions, a scientific analysis is. [50, 51]. Nevertheless, a scientific analysis on the effects of such models for businesses is still lacking. For both, suppliers and customers, the use of blockchain-based pay-per-use models would require adjustments in the area of supply chain management. Adaptions along the financial and information flow need to be made and the material flow may change entirely. Whether these adaptations can be described as disruptive and will lead to a large-scale change in customer-supplier relationships in future still needs to be investigated in more detail.

To engage with this problem, an overview of potential benefits and risks is an important first step. On this basis it will then be possible to question and challenge how corresponding models can be successfully integrated into existing and new processes. When exploring related research questions, one should consider some adjacent developments to ensure a preferably holistic view of the topic. Political regulations for the digital space, such as the introduction and use of digital currencies, can be cited as one example. The combination and functionality in interaction with technologies that are also useful for pay-per-use models, such as IoT, cloud or AI, should also be constantly kept in mind. Ultimately, the goal should be to develop a beneficial process that generates the desired added value independently of blockchain as a technology.

7 Blockchain and Additive Manufacturing

7.1 State of the Art

Blockchain technology appears to be particularly promising in combination with additive manufacturing (AM), as it has the potential to eliminate challenges associated with AM [52]. At the moment, additive manufacturing is largely taking place at the companies themselves. For the time being, this will continue to apply. A survey from Ernst & Young revealed that 56% of the companies surveyed want to continue producing their own products in the future, while 32% of the companies are also considering external manufacturers [53]. Besides a possible future change in the supply chain the worldwide increase in additive manufacturing is also having an impact on global trade. According to an analysis by the Dutch financial institution ING, global trade will decline approximately 23% by 2060, assuming the projected numbers of investments in 3D printers materialize [54].

In practice, the first companies are already recognizing the relevance of blockchain and AM in combination. Established companies as well as start-ups are therefore founding new companies or joining together to form large consortia in order to further research the combination of both technologies. The aim of the Genesis of Things (GoT) project, for example, is to develop a blockchain-based AM exchange platform that connects many independent printing facilities and enables participants to securely store and transfer AM design data on the blockchain. The platform enables companies to select the most suitable print provider for their production needs, place orders and process payments automatically [55]. Thyssenkrupp has developed the "Digital TechCenter for Additive Manufacturing" platform. In addition to consulting and construction services, the platform also offers 3D prints. The underlying concept is based on the International Data Spaces (IDS) and the Hyperledger Fabric as blockchain technology. This should ensure secure data transfer as well as traceability and immutability [56].

Scientific literature mainly deals with the question what changes result from the usage of AM and blockchain for physical supply chain processes, where blockchain is used for secure exchange of construction data and as an enabler of data sovereignty. Guo et al. describe blockchain technology as a promising solution for authentic transmission and protection of copyright for additive manufacturing processes, where blockchain acts as a secure interface between customer and manufacturer of digital twin data [57]. Kloeckner et al. deal with opportunities for business model innovation through blockchain and 3D printing. They show existing problems of business models for decentralized 3D printing with regard to intellectual property and secure data management and analyze which solutions blockchain offers. Additionally, they investigate platform solutions that dynamically exchange printing capacities between several players as required [58].

7.2 Research Discussion

Current industrial projects and related research exclusively deal with the usage of blockchain and its impact on the physical supply chain, where payment transactions play a subordinate role. The focus is primarily on data sovereignty and secure communication. Occasionally, publications on the effects on the financial sector can also be found. Plewnia and Köbernick highlight the importance of AM for the financial sector and the role of the bank [59]. There, however, the impact on the finance side of blockchain and AM is investigated to a limited extend. This indicates a gap for further research on how new AM business models affect the financial supply chain and how finance products will change. With the help of smart contracts, companies could synchronize their automated payments with regard to the transactions of construction plans and specifications. Should peer-to-peer payments become possible in a cross-organizational AM situation, blockchain-based smart contracts would make intermediaries such as banks superfluous. [60]. Therefore, it is of interest, what opportunities and challenges arise from the combined use of additive manufacturing processes and blockchain technology in the financial supply chain. These changes in the financial supply chain are leading to new potential business models for manufacturing companies and financial institutions within platform economies that needs to be researched more closely. Furthermore, it is of interest to determine the effects in pay-per-use approaches, but also for payment terms, financing and risk management.

Based on the previously mentioned problem statements, further questions arise in other areas that could be of interest as well. In case of new business models, current legal regulations need to be reviewed regarding how these may have to be adapted to enable such digital business models. In addition, blockchain offers the possibility of peer-to-peer payments and therefore it requires the development of a token economy in which automated payments are sent via M2M communication. This raises the question of how such a token economy is structured and how it can be used. The overriding question is to what extent such an implementation of blockchain solutions is economically viable. Therefore, economic viability has to be examined for enterprise AM solutions.

8 Decentralized Markets - Trust and Transaction Costs

8.1 State of the Art

Maintenance and production are competing domains in terms of the utilization of production resources such as maintenance capacity [62]. Past research is focusing on appropriate coordination structures to balance the utilization of machine capacity [61, 62]. Since the management of networks is an essential planning layer in the production planning, it is also conceivable that it can be adapted in the fields of maintenance [63]. Interorganizational networks allow industrial companies to cope with uncertainties by spreading the risk evoked by unexpected over- and undercapacities via a market-like capacity stock exchange [64]. Market-driven flexibility and willingness of its participants are determining the potentials of intercompany networks [65].

Uncertainties evoked by information asymmetries between the contractors lead to both, an increase of coordination effort as well as transaction costs and a reduction of trust [66, 67]. To avoid scenarios of instability, such as adverse selection [68], measures to reduce information asymmetries are needed. Trust can reduce social complexity [69] and leads to a reduction of transaction costs [67, 70]. The emergence of trust persist a long time, but its simplicity of breaking leads to a need in functionalities supporting the emergence and maintenance of trust in intercompany networks [71]. To encourage practitioners in the production, maintenance and adjacent domains in the fields of supply chain management to participate within a market-like intercompany network for negotiating capacity, the transaction costs resulting from subcontracting should be lower than the production costs [72, 73]. For that reason, trust becomes an important resource which determines the occurrence of such cooperations [74]. Trust can occur in different layer or levels, such as on an (inter-)personal and (inter-)organizational trust [75–77] whereas in the fields of sharing economy, trust can be differed between trust in peers, platform and trust in the product [78, 79].

To cope with challenges of information asymmetry, emerging technologies such as blockchain technology receives closer consideration, especially in the fields of decentralized markets [80–83]. The data stored within the Blockchain serves as a basis for reducing information asymmetries "*after the transaction and provides a solid basis for performance evaluation, benchmarking and auditing*" and thus contributes in the decrease of behavioral uncertainties [3, p. 6]. However, transparency in the information shared can be both a source for trust and also a source of exploitation [84]. In accordance with *Schmid & Wagner*, an important research question is the influence of blockchain in terms of outsourcing decisions [3]. Apart from supply chains, a transition to adjacent domains in the industrial domains such as the production and maintenance needs to receive closer consideration.

8.2 Research Discussion

It can be stated that a plethora of contributions address the role of trust in the industrial value creation domain, however without concretizing it in detail in conjunction with the capacity exchange. Domain-related contributions indicates that concepts such as intercompany capacity exchange rely on trust and thus requires further investigations about how to ensure it [64]. Recent literature investigated the potential contributions of Blockchain to increase trust in the sharing economy, decentralized markets or intercompany networks [80, 82, 85, 86]. However, the lack of research of blockchain adoption in the fields of maintenance [87] drives research of information asymmetries in the field of capacity exchange of technical services. Preliminary suggestions aligning the Blockchain within the procurement of technical services have been taken up in [88].

Against this backdrop, a research of interest lies within the clarification of the extent in which blockchain ensures trust in outsourcing tasks in the industrial domains and how does a specific blockchain solution has to look like?

To measure the impact of blockchain based solutions in terms of utility, more profound investigations is required with a special emphasis on building and evaluating concrete blockchain based artifacts. Subsequent research allows the derivation of reliable statements in terms of the extend Blockchain can contribute in the emergence or rather maintenance of trust in interorganizational negotiation. A motivation made by the paradigm of Design Science is to extent or rather re-use the existent knowledge base instead of deriving already existing artifacts to known solutions with low degree of maturity [89–91]. The herein proposed state of the art proofs the relevance of DLT-concepts such as Blockchain [92], deserves more attention. It provides a starting point for improving or extending preliminary thoughts of designing blockchain-based artifacts in conjunction with decentralized market from a sociotechnical point of view. This entails the realization and ex-post evaluation of concrete solutions in both artificial and naturalistic environment [93], which herein are Blockchain-based artifacts with a focus on measuring the utility in terms of efficiency due its information-asymmetry reducing characteristics [3, 86] and its impacts on increase the efficiency in outsourcing tasks.

Further investigations could take place in the fields of CPPS, which is partly addressed in recent investigations [94] but is taken up more profoundly in the following chapter.

9 Blockchain-Based Cyber-Physical Production Systems

9.1 State of the Art

In supply chains suppliers, producers and customers are tightly interwoven and dependent on each other. In the course of increasing production variety and decreasing lot size, cyber-physical production systems (CPPS) have emerged that enable flexible, automated and self-configuring production [95]. Even though such systems have gained a lot of recent attention [95–98], several challenges such as trustworthy cross-company interactions, data security, robustness against failures or transparent and reliably documented processes remain unsolved [99]. Blockchain technology as a distributed ledger presents a potential solution to these issues, due to its irreversible, redundant and distributed data storage [100]. The potential of combining cyber-physical systems (CPS) with blockchain technology has been recognized in the literature [101, 102], even though there is little literature on blockchain technology in CPPS [100, 103, 104]. Most authors focus either on robot transactions [105, 106], technical features of blockchain in CPS

[102] or on single use cases such as pay-per-use [107, 108], but do not provide a holistic and practically driven overview of blockchain in CPPS.

For blockchain-based robot transactions, blockchain is used to strengthen the robot coalition algorithm [105]. In the proposed theoretical solution, smart contracts in a publish/subscribe network allow robots in a CPS obtain the overall view and reconfigure on the fly. The contracts are used for task distribution between robots, resource allocation and monitoring of task execution. Pacheco et al. propose a blockchain based robot interaction experiment with a byzantine fault tolerance (BFT) consensus mechanism [106]. In this experiment robots should detect black tiles in an arena. To compute this, robots have to deposit currency to perform an action and receive payment from a smart contract for a successful operation. If a robot does not receive payment for a few times, it will run out of gas and be declared faulty. The communication between robots is realized in a decentralized ad-hoc network. In the setting of CPS the literature presents common challenges of blockchain technology and proposes solutions such as traceability, scalability, security, inaccurate sensor data, lack of granularity or lack of automation, but is not going into detail about the implementation [101]. Barenji et al. present an implementation of a peer-to-peer blockchain network for geographically distributed 3D printing companies [102]. To prevent saving different data structures onto a blockchain, they use an intermediate communication layer, which translates machine-specific language into a common language. This adapter also guarantees security, as it only allows access to specific sets of commands. To improve trust, every order information is stored and processed on a blockchain via smart contracts. In a case study they compare the overall performance as well as two different consensus mechanisms.

Blockchain can also be used as a decentralized marketplace and can improve the pay-per-use method. In a proof-of-concept based on Ethereum smart contracts Ranganthan et al. present a solution to common issues of fees for listing and selling [107]. They also improve the privacy for user data by using tokens instead of clear data. This solution is compared to well-known platforms like eBay and it turns out that selling using a blockchain-based solution is cheaper. Gong et al. also consider the trading aspect and provide a case study on machine-to-machine (M2M) autonomous trading [108]. They carry out a proof-of-concept of such trading via smart contracts and propose a layered architecture for the combination of IoT and blockchain, which they call an 'IoT-Blockchain fusion model'. Privacy issues are not considered and the proof-of-concept is provided by an implementation with Raspberry Pi's. With regard to the use of blockchain technology in CPPS, Afanasev et al. propose a blockchain architecture for CPPS based on the blockchain framework Ethereum [103]. They test the Ethereum network as a backbone for the CPPS and point out several open issues regarding performance and security. Based on this research, a use case for manufacturing including M2M communication is developed [100]. A physical prototype of M2M communication or a blockchain-based CPPS is not implemented. Lee et al. propose a three-layered blockchain architecture for manufacturing systems and carry out a case study in manufacturing machines [99]. Additionally, they present several challenges in blockchain implementation such as real-time implementation, storage capacity and lack of knowledge and infrastructure. Bayhan et al. empathize the theoretical potential of a blockchain-based CPPS and propose the implementation in a physical test field at their university [104].

9.2 Research Discussion

The literature reveals that current research on blockchain-based CPPS either remains on a theoretical level or studies only the implementation of individual components of such a system. This raises several questions regarding the actual impact of blockchain technology on a CPPS and the implementation process. Even though the theoretical potential of blockchain in a CPPS has been revealed, an extensive use case combining the feasible potential has not yet been developed. Thus, it is not evident if the actual impact of blockchain on the CPPS matches its theoretical potential in terms of transparency, automation and security. Additionally, the implementation process and its challenges regarding the combination of an existing CPPS and blockchain technology remain unclear. This includes the design of a suitable blockchain architecture for a CPPS taking into consideration features such as performance, scalability, security and the connection and interaction of heterogeneous IoT devices to and with blockchain. Related research fields such as pay-per-use for robots for performance-based billing or negotiation on decentralized markets relating to free production or storage capacity are also of interest.

10 Consolidation and Assignment to Scientific Layers

To consolidate and structure the prior presented research topics, Fig. 2 assigns them to scientific layers that are prominently used in blockchain research. The presented framework is adopted from Hawlitschek et al. [82] and builds up on a previous work of Notheisen et al. [109]. It consists of a six layered structure, starting with an environment or rather macro layer, in which the constraints and general conditions are clarified. This is followed by the infrastructure layer consisting of soft- and hardware- as well as IT security-related topics. Finally, an application layer is dealing with interactions between actors and the blockchain platform and an agent layer mapping these interactions [109, 110].

Attached to the four layers, the extended framework includes an additional behavioral layer and a so-called trust frontier, which separates the real intentions of the agents from the interactions deposited inside the blockchain platform and allows a more detailed analysis on behavioral aspects [82]. Referring to the seven research topics of this paper, an assignment has been made by highlighted circles on the left side of the graphic. As the figure reveals, no research topic solely entails all layers. However, all layers are at least considered by one research topic. The strategic topics mainly focus on the environmental layer with socio-economic and legal impact, but also have a distribution over most of the other layers. The application-oriented topics mainly deal with interactions among agents and also cover the infrastructure layer partly. Least consideration is found in the trust frontier, followed by the behavioral and infrastructure layers.

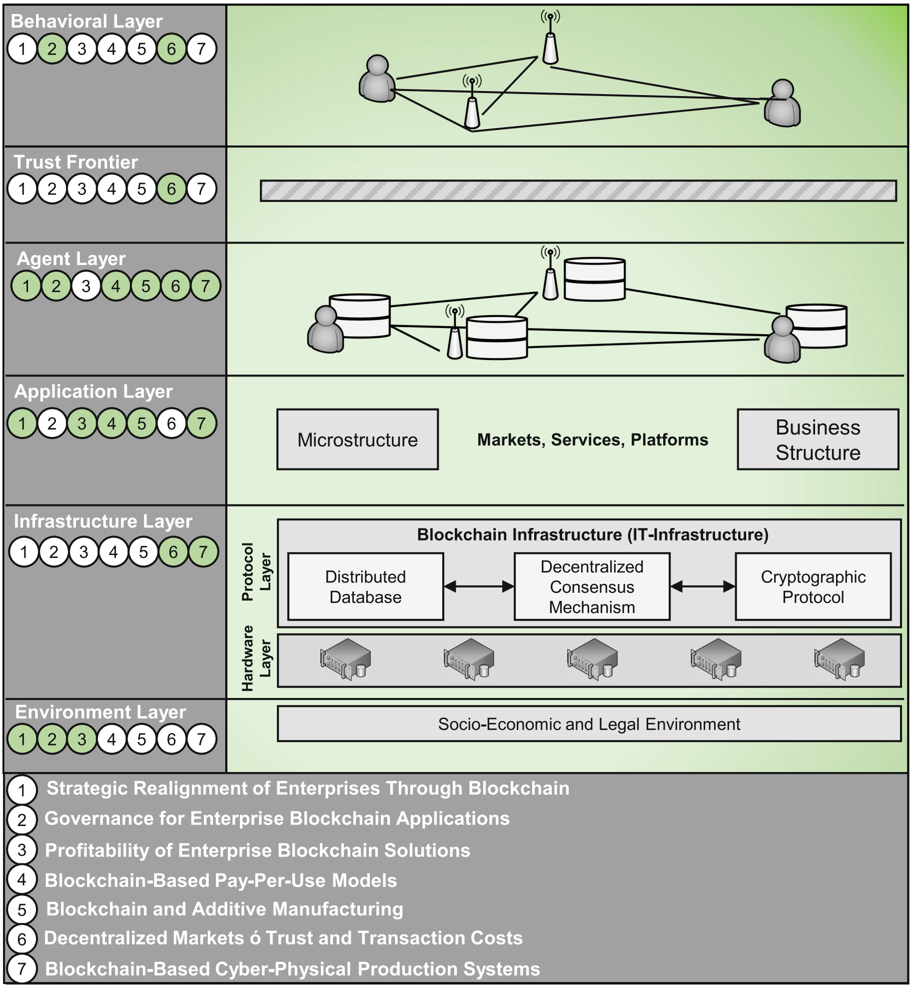

Fig. 2. Scientific layers of blockchain research, based on [82]

11 Conclusion

The paper reveals an overview of central research topics in the field of blockchain and supply chain management and offers a detailed state of the art and a research discussion for each topic as well as future research directions. In order to identify thematic intersections between different research topics, Fig. 1 can be used to classify topics as strategic or application oriented and Fig. 2 to find a common ground within several scientific layers of blockchain research. To give an outlook and sum up the research needs for blockchain in supply chain management, it will be necessary to not only have a strategic realignment to more decentralization, but also to go through comprehensive change management cycles that need to be observed from different perspectives. Moreover, the interplay of 'governance by blockchain' and 'governance of blockchain' needs further investigation, and therefore especially to what extend smart contracts can be used on different utilization degrees and for different verification purposes. Again, at this point different perspectives (technical, organizational, compliance and regulatory) are needed for a comprehensive observation and assessment. Especially on the technical side privacy-preserving techniques to maintain data sovereignty need to be analyzed more intensely. Further research is required in profitability considerations that have to cover the value of the exchanged data and thereby consider network effects over multiple stakeholders. These stakeholders need to be identified, classified and analyzed with respect to their position in the supply chain. When it comes to business models, pay-per-use-models need further investigation especially when considering applications for specific use cases like 3D-printing or other Blockchain-powered platforms. Here again, profitability statements need to be developed in order to demonstrate best practices. Finally, the concepts to bring together supply chain partners in commerce via decentralized markets or in the production field via blockchain-powered cyber-physical production systems need more consideration, especially when it comes to measuring information-asymmetry or enabling performance-based billing and negotiation processes.

Acknowledgements. The work was funded by the Ministry of Economic Affairs, Innovation, Digitalization and Energy of the State of North Rhine-Westphalia.

References

1. Klink, P.: FAST RAMP-UP: Anlaufmanagement nach disruptiven pandemischen Ereignissen. Whitepaper im Rahmen des Forschungsprojekts "Fast Ramp-Up". Fraunhofer-Gesellschaft (2020)
2. Guerpinar, T., Guadiana, G., Ioannidis, P. et al.: The current state of blockchain applications in supply chain management. In: International Conference on Blockchain Technology, Shanghai, China (2021). https://doi.org/10.1145/3460537.3460568
3. Schmidt, C.G., Wagner, S.M.: Blockchain and supply chain relations: a transaction cost theory perspective. J. Purch. Supply Manage. **25**, 100552 (2019). https://doi.org/10.1016/j.pursup.2019.100552
4. Treleaven, P., Gendal Brown, R., Yang, D.: Blockchain technology in finance. Computer **50**, 14–17 (2017). https://doi.org/10.1109/MC.2017.3571047
5. DIN SPEC 16597 Terminology for blockchains; Text in English. Beuth Verlag, Berlin
6. Pai, S., Buvat, J., Lise, O., et al.: Is blockchain the key to a new age of transparency and trust in the supply chain?: How organizations have moved from blockchain hype to reality (2018)
7. Düdder, B., Fomin, V., Gürpinar, T., et al.: Interdisciplinary blockchain education: utilizing blockchain technology from various perspectives. Front Blockchain 3 (2021) https://doi.org/10.3389/fbloc.2020.578022
8. Gürpinar, T., Harre, S., Henke, M., et al.: Blockchain technology – integration in supply chain processes. TUHH Universitätsbibliothek (2020)
9. Gürpinar, T., Straub, N., Kaczmarek, S., et al.: Blockchain-Technologie im interdisziplinären Umfeld. ZWF **114**, 605–609 (2019)https://doi.org/10.3139/104.112117
10. Klinger, P., Bodendorf, F.: Blockchain-based cross-organizational execution framework for dynamic integration of process collaborations. In: Gronau, N., Heine, M., Poustcchi, K. et al. (eds.) WI2020 Zentrale Tracks. GITO Verlag, pp. 1802–1817 (2020)

11. Kewell, B., Adams, R., Parry, G.: Blockchain for good? Strateg. Chang. **26**, 429–437 (2017). https://doi.org/10.1002/jsc.2143
12. Herian, R.: Blockchain and the (re)imagining of trusts jurisprudence. Strateg. Chang. **26**, 453–460 (2017). https://doi.org/10.1002/jsc.2145
13. Casino, F., Dasaklis, T.K., Patsakis, C.: A systematic literature review of blockchain-based applications: current status, classification and open issues. Telematics Inform. **36**, 55–81 (2019). https://doi.org/10.1016/j.tele.2018.11.006
14. Müller, A., Graumann, M., Weiß, H.-J.: Innovationen für eine digitale Wirtschaft. Springer Fachmedien Wiesbaden, Wiesbaden (2020)
15. Weill, P.D.: Don't just lead, govern: how top-performing firms govern it. MIS Q. Exec. **3**, 1–17 (2004)
16. Schmahl, A., Mohottala, S., Burchardi, K., et al.: Resolving the blockchain paradox in transportation and logistics (2019)
17. de Reuver, M., Sørensen, C., Basole, R.: The digital platform: a research agenda. J. Inf. Technol. **33**, 124–135 (2018)
18. Parker, G., van Alstyne, M.: Innovation, openness, and platform control. Manage. Sci. **64**, 3015–3032 (2018)
19. Gasser, U., Budish, R., West, S.: Multistakeholder as Governance Groups: Observations from Case Studies. Berkman Center Research Publication (2015)
20. Andersen, J.V., Bogusz, C.I.: Self-organizing in blockchain infrastructures: generativity through shifting objectives and forking. J. Assoc. Inf. Syst. **20**, 1242–1273 (2019)
21. Cui, Z., Fei, X.U., Zhang, S., et al.: A hybrid blockchain-based identity authentication scheme for multi-WSN. IEEE Trans. Serv. Comput. **13**, 241–251 (2020)
22. German Federal Ministry for Economic Affairs and Energy: Blockchain strategy of the federal government - we set out the course for the token economy (2019)
23. Beck, R., Müller-Bloch, C., King, J.L.: Governance in the blockchain economy: a framework. J. Assoc. Inf. Syst. **19**, 1020–1034 (2018)
24. Yermack, D.: Corporate governance and blockchains. Rev. Finan. **21**, 7–31 (2017)
25. Pelizza, A., Kuhlmann, S.: Mining governance mechanisms: innovation policy, practice, and theory facing algorithmic. In: Handbook of Cyber-Development, Cyber-Democracy, and Cyber-Defense Decision-Making, pp. 495–517
26. de Filippi, P., McMullen, G.: Governance of blockchain systems: Governance of and by Distributed Infrastructure, Blockchain Research Institute and COALA (2018)
27. Fill, H.-G., Meier, A.: Blockchain: Grundlagen, Anwendungsszenarien und Nutzungspotenziale. Edition HMD (2020)
28. Pedersen, A., Risius, M., Beck, R.: A ten-step decision path to determine when to use blockchain technologies. MISQE **18**, 99–115 (2019). https://doi.org/10.17705/2msqe.00010
29. Schlecht, L., Schneider, S., Buchwald, A.: The prospective value creation potential of Blockchain in business models: a delphi study. Technol. Forecast. Soc. Chang. **166**, 120601 (2021). https://doi.org/10.1016/j.techfore.2021.120601
30. Thommen, J.P., Achleitner, A.K.: Allgemeine Betriebswirtschaftlehre, 6th edn. Gabler Verlage, Wiesbaden (2009)
31. Scholz-Reiter, B., Gorldt, C., Hinrichs, U., et al.: RFID - Einsatzmöglichkeiten und Potentiale in logistischen Prozessen (2007)
32. Peukert, S., Treber, S., Balz, S., Haefner, B., Lanza, G.: Process model for the successful implementation and demonstration of SME-based industry 4.0 showcases in global production networks. Prod. Eng. Res. Devel. **14**(3), 275–288 (2020). https://doi.org/10.1007/s11740-020-00953-0
33. Irfan, M., Wang, M., Zafar, A.U., et al.: Modeling the enablers of supply chain strategies and information technology: improving performance through TISM approach. VJIKMS **51**, 461–491 (2021). https://doi.org/10.1108/VJIKMS-06-2019-0082

34. Raut, R.D., Priyadarshinee, P., Gardas, B.B., et al.: Analyzing the factors influencing cloud computing adoption using three stage hybrid SEM-ANN-ISM (SEANIS) approach. Technol. Forecast. Soc. Chang. **134**, 98–123 (2018). https://doi.org/10.1016/j.techfore.2018.05.020
35. Mishra, A.N., Pani, A.K.: Business value appropriation roadmap for artificial intelligence. VJIKMS **51**, 353–368 (2021). https://doi.org/10.1108/VJIKMS-07-2019-0107
36. Platzer, J.: Bitcoin kurz & gut: Banking ohne Banken, 1st edn. O'Reilly, Köln (2014)
37. Kesten, R., Müller, A., Schröder, H.: IT-Controlling: IT-Strategie, Multiprojektmanagement, Projektcontrolling und Performancekontrolle, 2nd edn. Vahlen, München (2013)
38. Klischewski, R.: Blockchains zwischen Anarchie und Governance: Steuerungsansätze für die öffentliche Verwaltung. In: Multikonferenz Wirtschaftsinformatik, Lüneburg, pp. 609–620 (2018)
39. Andrian, H.R., Kurniawan, N.B.: Blockchain technology and implementation : a systematic literature review. In: 2018 International Conference on Information Technology Systems and Innovation (ICITSI), pp. 370–374 (2018)
40. Queiroz, M.M., Telles, R., Bonilla, S.H.: Blockchain and supply chain management integration: a systematic review of the literature. Supp Chain Mnagmnt **25**, 241–254 (2019). https://doi.org/10.1108/SCM-03-2018-0143
41. Cole, R., Stevenson, M., Aitken, J.: Blockchain technology: implications for operations and supply chain management. Supp Chain Mnagmnt **24**, 469–483 (2019). https://doi.org/10.1108/SCM-09-2018-0309
42. Mika, B., Goudz, A.: Blockchain-Technologie in der Energiewirtschaft: Blockchain als Treiber der Energiewende, 1st ed. 2020 (2020)
43. Schmeiss, J.: Will Blockchain Disrupt Your Business? Zenodo (2018)
44. Ematinger, R.: Von der Industrie 4.0 zum Geschäftsmodell 4.0. Springer Fachmedien Wiesbaden, Wiesbaden (2018)
45. Simon, H.: Preismanagement in digitalen geschäftsmodellen. In: Bruhn, M., Hadwich, K.: (eds) Dienstleistungen 4.0. Springer Fachmedien Wiesbaden, Wiesbaden, pp. 261–274 (2017)
46. Commerzbank, A.G.: Pressemitteilung: commerzbank bietet als erste deutsche Bank neue datenbasierte Kredite für Firmenkunden an (2018) https://www.commerzbank.de/de/hauptnavigation/presse/pressemitteilungen/archiv1/2018/quartal_18_02/presse_archiv_detail_18_02_75466.html Accessed 28 Sep 2021
47. Commerzbank, A.G.: Bank mit dem Blockchain-Blick (2019) https://www.commerzbank.ae/portal/media/corporatebanking/auslandsseiten/oesterreich/news/2020-5/ASPEKTE_012019_6-28-29-Commerzbank2.pdf
48. Kehler, M., Regier, S., Stengel, I.: An innovative IoT based financing model for SMEs. In: Proceedings of the 6th Collaborative European Research Conference (CERC 2020), pp. 361–370 (2020)
49. Sato, K., Nakashima, K.: Optimal pricing problem for a pay-per-use system based on the Internet of Things with intertemporal demand. Int. J. Prod. Econ. **221**, 107477 (2020). https://doi.org/10.1016/j.ijpe.2019.08.012
50. Knapp, M., Greiner, T., Yang, X.: Pay-per-use sensor data exchange between IoT devices by blockchain and smart contract based data and encryption key management. In: 2020 International Conference on Omni-layer Intelligent Systems (COINS). IEEE, pp. 1–5 (2020)
51. Guha, K., Saha, D., Chakrabarti, A.: Blockchain technology enabled pay per use licensing approach for hardware IPs. In: 2020 Design, Automation & Test in Europe Conference & Exhibition (DATE). IEEE, pp. 1618–1621 (2020)
52. Alkhader, W., Alkaabi, N., Salah, K., et al.: Blockchain-based traceability and management for additive manufacturing. IEEE Access **8**, 188363–188377 (2020). https://doi.org/10.1109/ACCESS.2020.3031536

53. Ernst & Young GmbH: EY´s Global 3D Prinitng Report 2019 (2019)
54. ING Bank NV: 3D printing: a threat to global trade: Locally printed goods could cut trade by 40% (2017)
55. Stöcker, C., Blechschmidt, B.: Erfahrungsbericht Genesis of Things Project: Ansätze und Herausforderungen bei der Integration von Blockchain in der additiven Fertigung und Geschäftsmodelle (2018)
56. Marx, K.: Herr der Daten: So sichert die Blockchain smarte Produktionsverfahren ab (2019)
57. Guo, D., Shiquan, L., Hao, L., et al.: A framework for personalized production based on digital twin, blockchain and additive manufacturing in the context of Industry 4.0. Unpublished (2020)
58. Klöckner, M., Kurpjuweit, S., Velu, C., et al.: Does blockchain for 3D printing offer opportunities for business model innovation? Res. Technol. Manag. **63**, 18–27 (2020). https://doi.org/10.1080/08956308.2020.1762444
59. Main Incubator GmbH: Gedruckte Disruption: Additive Fertigung und die Finanzdienstleistungen (2020)
60. Ganne, E.: Can blockchain revolutionize international trade? (2018)
61. Kurz, M.: Koordination zwischen Instandhaltung und Produktion mittels Handelsmechanismus: Coordination between maintenance and production by means of a trading mechanism, 1. Auflage. Schriftenreihe Rationalisierung, Band 152. Apprimus Verlag, Aachen (2018)
62. Schuh, G., Kurz, M., Jussen, P., Defèr, F.: Coordination between maintenance and production by means of auction mechanisms for increased efficiency of production systems. In: Mathew, J., Lim, C.W., Ma, L., Sands, D., Cholette, M.E., Borghesani, P. (eds.) Asset Intelligence through Integration and Interoperability and Contemporary Vibration Engineering Technologies. LNME, pp. 545–554. Springer, Cham (2019). https://doi.org/10.1007/978-3-319-95711-1_54
63. Gassner, S.: Instandhaltungsdienstleistungen in Produktionsnetzwerken. Springer Fachmedien Wiesbaden, Wiesbaden (2013)
64. Uygun, Y.: Integrierte Kapazitätsbörse - Entwicklung eines Instrumentariums für den Handel mit Maschinenkapazitäten in regional-lateralen Unternehmensnetzen. Zugl.: Dortmund, Techn. Univ., Diss., 2012. Fabrikorganisation. Verl. Praxiswissen, Dortmund (2012)
65. Siebert, H.: Ökonomische analyse von unternehmensnetzwerken. In: Sydow, J. (ed.) Management von Netzwerkorganisationen, pp. 7–27. Gabler Verlag, Wiesbaden (2010)
66. Eisenhardt, K.M.: Agency theory: an assessment and review. Acad. Manag. Rev. **14**, 57–74 (1989)
67. Cai, R.: Trust and transaction costs in industrial districts (2004)
68. Akerlof, G.A.: The market for “lemons”: quality uncertainty and the market mechanism. In: Uncertainty in economics. Elsevier, pp. 235–251 (1978)
69. Luhmann, N.: Vertrauen: Ein Mechanismus der Reduktion sozialer Komplexität, 5. Aufl. UTB, vol 2185. UVK-Verl.-Ges; UTB, Konstanz, Stuttgart (2014)
70. Lee, J., Kim, J., Moon, J.Y.: What makes Internet users visit cyber stores again? Key design factors for customer loyalty. In: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, pp. 305–312 (2000)
71. Lewicki, R.J., Bunker, B.B.: Trust in relationships: a model of development and decline. Jossey-Bass (1995)
72. Suematsu: Transaction Cost Management (2014)
73. Bretzke, W.-R.: Die möglichen Kostenvorteile der Fremdvergabe. In: Bretzke, W.-R. (ed.) Logistische Netzwerke. Springer, Heidelberg, pp. 477–493 (2020)https://doi.org/10.1007/978-3-662-59757-6_28
74. Duschek, S., Wetzel, R., Aderhold, J.: Probleme mit dem Netzwerk und Probleme mit dem Management: Ein neu justierter Blick auf relevante Dilemmata und auf Konsequencen für die

Steuerung. In: Aderhold, J., Meyer, M., Wetzel, R. (eds.) Modernes Netzwerkmanagement, pp. 143–164. Gabler Verlag, Wiesbaden (2005)
75. Loose, A., Sydow, J.: Vertrauen und Okonomie in Netzwerkbeziehungen- Strukturationstheoretische Betrachtungen. In: Sydow, J., Windeler, A. (eds.) Management interorganisationaler Beziehungen, pp. 160–193. VS Verlag für Sozialwissenschaften, Wiesbaden (1997)
76. Schweer, M.K.W.: Vertrauen als Organisationsprinzip in interorganisationalen Kooperationen. In: Schilcher, C., Will-Zocholl, M., Ziegler, M. (eds.) Vertrauen und Kooperation in der Arbeitswelt, pp. 103–121. VS Verlag für Sozialwissenschaften, Wiesbaden (2012)
77. Zaheer, A., McEvily, B., Perrone, V.: Does trust matter? Exploring the effects of interorganizational and interpersonal trust on performance. Organ. Sci. **9**, 141–159 (1998)
78. Hawlitschek, F., Teubner, T., Weinhardt, C.: Trust in the sharing economy. Die Unternehmung **70**, 26–44 (2016). https://doi.org/10.5771/0042-059X-2016-1-26
79. Große, N., Guerpinar, T., Henke, M.: Blockchain-enabled trust in intercompany networks applying the agency theory. In: 3rd Blockchain and Internet of Things Conference (2021). https://doi.org/10.1145/3475992.3475994
80. Notheisen, B.: Engineering Decentralized Markets - A Blockchain Approach (2019)
81. Subramanian, H.: Decentralized blockchain-based electronic marketplaces. Commun ACM **61**, 78–84 (2018). https://doi.org/10.1145/3158333
82. Hawlitschek, F., Notheisen, B., Teubner, T.: The limits of trust-free systems: a literature review on blockchain technology and trust in the sharing economy. Electron. Commer. Res. Appl. **29**, 50–63 (2018). https://doi.org/10.1016/j.elerap.2018.03.005
83. DIN SPEC 3103: Blockchain und Distributed Ledger Technologien in Anwendungsszenarien für Industrie 4.0. Beuth Verlag, Berlin (2019)
84. Notheisen, B., Weinhardt, C.: The blockchain, plums, and lemons: information asymmetries & transparency in decentralized markets. Karlsruhe (2019)
85. Mehrwald, P., Treffers, T., Titze, M., et al.: Application of blockchain technology in the sharing economy: a model of trust and intermediation. In: Proceedings of the 52nd Hawaii International Conference on System Sciences (2019)
86. Wieninger, S.: Vertrauen in Unternehmensnetzwerken durch Blockchain-Technologie. Apprimus Wissenschaftsverlag (2020)
87. Abbas, Y., Martinetti, A., Moerman, J.-J., et al.: Do you have confidence in how your rolling stock has been maintained? A blockchain-led knowledge-sharing platform for building trust between stakeholders. Int. J. Inf. Manage. **55**, 102228 (2020). https://doi.org/10.1016/j.ijinfomgt.2020.102228
88. Große, N.: Einsatz der Blockchain zur Schaffung von Vertrauen im Beschaffungsprozess technischer Dienstleistungen . In: Instandhaltungsforum, InFo 2021 Connected. Tagungsband. Fraunhofer-Gesellschaft, pp. 7–13 (2021)
89. Iivari, J., Hansen, M.R.P., Haj-Bolouri, A.: A framework for light reusability evaluation of design principles in design science research. In: Proceedings of International Conference on Design Science Research in Information Systems and Technology (DESRIST 2018) (2018)
90. Iivari, J., Rotvit Perlt Hansen, M., Haj-Bolouri, A.: A proposal for minimum reusability evaluation of design principles. Eur. J. Inf. Syst. **30**, 286–303 (2021)
91. Gregor, S., Hevner, A.R.: Positioning and presenting design science research for maximum impact. MIS Q. 337–355 (2013)
92. Kannengießer, N., Lins, S., Dehling, T., et al.: What does not fit can be made to fit! Trade-offs in distributed ledger technology designs. In: Bui, T. (ed.) Proceedings of the 52nd Hawaii International Conference on System Sciences. Hawaii International Conference on System Sciences (2019)
93. Pries-Heje, J., Baskerville, R., et al.: Strategies for design science research evaluation. In: ECIS 2008 Proceedings, vol. 87 (2008)

94. Große, N., Leisen, D., Gürpinar, T., et al.: Evaluation of (De-) centralized IT technologies in the fields of cyber-physical production systems (2020). https://doi.org/10.15488/9640
95. Müller, T., Jazdi, N., Schmidt, J.-P., et al.: Cyber-physical production systems: enhancement with a self-organized reconfiguration management. Procedia CIRP **99**, 549–554 (2021). https://doi.org/10.1016/j.procir.2021.03.075
96. Meissner, H., Aurich, J.C.: Implications of cyber-physical production systems on integrated process planning and scheduling. Procedia Manuf. **28**, 167–173 (2019). https://doi.org/10.1016/j.promfg.2018.12.027
97. Lins, T., Oliveira, R.A.R.: Cyber-physical production systems retrofitting in context of Industry 4.0. Comput. Ind. Eng. **139**, 106193 (2020). https://doi.org/10.1016/j.cie.2019.106193
98. Rojas, R., Rauch, E., Matt, D.T.: Research fields and challenges to implement cyber-physical production systems in SMEs: a literature review. In: CMUJNS 20 (2021). https://doi.org/10.12982/CMUJNS.2021.022
99. Lee, J., Azamfar, M., Singh, J.: A blockchain enabled cyber-physical system architecture for Industry 4.0 manufacturing systems. Manuf. Lett. **20**, 34–39 (2019). https://doi.org/10.1016/j.mfglet.2019.05.003
100. Afanasev, M.Y., Fedosov, Y.V., Krylova, A.A., et al.: An application of blockchain and smart contracts for machine-to-machine communications in cyber-physical production systems. In: Systems IICoIC-P (ed.) Proceedings 2018 IEEE Industrial Cyber-Physical Systems (ICPS): ITMO University, Saint Petersburg, Saint Petersburg, Russia, 15–18 May 2018. IEEE, Piscataway, NJ, pp. 13–19 (2018)
101. Dedeoglu, V., Dorri, A., Jurdak, R., et al.: A Journey in applying blockchain for cyberphysical systems. In: 2020 International Conference on Communication Systems & Networks (COMSNETS): 2020 International Conference on Communication Systems & Networks (COMSNETS) took place 7–11 January 2020 in Bangalore, India, Piscataway, NJ, pp. 383–390. IEEE (2020)
102. Barenji, A.V., Li, Z., Wang, W.M., et al.: Blockchain-based ubiquitous manufacturing: a secure and reliable cyber-physical system. Int. J. Prod. Res. **58**, 2200–2221 (2020). https://doi.org/10.1080/00207543.2019.1680899
103. Afanasev, M.Y., Krylova, A.A., Shorokhov, S.A., et al.: A design of cyber-physical production system prototype based on an ethereum private network. In: Balandin, S.I. (ed.) Proceedings of the 22nd Conference of Open Innovations Association FRUCT: Jyväskylä, Finland, 15–18 May 2018. FRUCT Oy, Finland, pp. 3–11 (2018)
104. Bayhan, H., Schulze Forsthövel, R., Kaiser, P., et al.: Blockchainbasierte cyberphysische Produktionssysteme. Logistics J. Proc. (2020). https://doi.org/10.2195/lj_Proc_bayhan_de_202012_01
105. Smirnov, A., Teslya, N.: Robot interaction through smart contract for blockchain-based coalition formation. In: Chiabert, P., Bouras, A., Noël, F., Ríos, J. (eds.) PLM 2018. IAICT, vol. 540, pp. 611–620. Springer, Cham (2018). https://doi.org/10.1007/978-3-030-01614-2_56
106. Pacheco, A., Strobel, V., Dorigo, M.: A blockchain-controlled physical robot swarm communicating via an ad-hoc network. In: Dorigo, M., et al. (eds.) ANTS 2020. LNCS, vol. 12421, pp. 3–15. Springer, Cham (2020). https://doi.org/10.1007/978-3-030-60376-2_1
107. Ranganthan VP, Dantu R, Paul A et al. (2018) A Decentralized Marketplace Application on the Ethereum Blockchain. In: 2018 IEEE 4th International Conference on Collaboration and Internet Computing (CIC). IEEE, [Place of publication not identified], pp 90–97
108. Gong, X., Liu, E., Wang, R.: Blockchain-based IoT application using smart contracts: case study of M2M autonomous trading. In: 2020 5th International Conference on Computer and Communication Systems: ICCCS 2020: Shanghai, China, May 15–18, 2020, pp. 781–785. IEEE Press, Piscataway, NJ (2020)

109. Notheisen, B., Hawlitschek, F., Weinhardt, C.: Breaking down the blockchain hype-towards a blockchain market engineering approach (2017)
110. Gürpinar, T., Austerjost, M., Kamphues, J., Maaßen, J., Yildirim, F., Henke, M.: Blockchain technology as the backbone of the internet of things - A taxonomy of blockchain devices. In: Conference on Production Systems and Logistics, Vancouver, Canada (2022)