Increasing the Utilization of Additive Manufacturing Resources through the Use of Blockchain Technology for a Production Network

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Abstract. The blockchain technology enables a common data basis between the participants. Entries are logged and the authenticity of the participants is guaranteed. In the case of a relationship between customers and producers, this would lead to verifiable cooperation, which would be a major step as companies enter into service contracts based on the flow of many small transactions through communication. This paper proposes an architecture that enables the creation and processing of orders between the customer and producers via a blockchain-based production network. The handling of larger files which are traceable via the blockchain is also shown and the use of a public or permissioned blockchain for an application case is also considered.

Keywords: Production network, Blockchain, Smart contract, Secure data exchange

1 Introduction

Companies face several challenges in acquiring innovative technologies such as additive manufacturing technology (AM). In addition to high initial investments, the development of know-how, the risk of unused capacity at low capacity utilization is also a potential problem [1]. Especially high market prices of suppliers prevent access to the integration of innovative production technologies into the own added value [2]. To overcome this problem, the capacity utilization of production lines within a company must be analyzed and optimized in the best possible way. For cross-company and cross-industry use, product and order data must be mapped in an access-safe manner in order to offer new potential benefits. Since outsourcing production orders usually involves considerable organizational effort, companies are often forced to build up more production capacity than is actually needed to meet the required delivery dates. As a result, production facilities are often used inefficiently [3]. From these problems, the following research questions can be derived:

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- How can innovative production capacities be offered to a wide range of users without intermediaries?
- Is it possible to process orders between customers and manufacturers using Smart Contracts?
- Would a public or private blockchain be more suitable for a production network?
- How to establish a secure data exchange for larger data volumes for the models to be produced between customer and manufacturer in connection with the blockchain?

In this article, we explain how blockchain technology can be used to build up the joint use of production data for efficient utilization of the capacities in a production network using the additive manufacturing facilities as an example. We propose an architecture that connects manufacturing companies and customers without middlemen while at the same time enables economic optimization of production capacities via an open block-chain-based production network with secure product and order data transfers. We also address the problem of handling large amounts of data between the respective parties. For this purpose, a blockchain-based mechanism is presented in which data is stored outside the blockchain, but can still be traced and stored in a secure manner via the blockchain. For the proposed structure and mechanism, a proof-of-concept prototype is presented in the Implementation section, the feasibility and effectiveness of which will be demonstrated experimentally.

2 The Key Terms and Definitions Used

Additive Manufacturing

Additive manufacturing (AM), also known as 3D printing and rapid manufacturing, describes a group of manufacturing technologies that can produce complex objects by automatically adding layered material until a three dimensional object is printed. Compared to traditional manufacturing, AM offers the advantage of producing parts directly and without special tools using a variety of materials such as plastic, metal or ceramics. In recent years, AM has evolved from an application for the rapid prototyping to a manufacturing technology for the production of quality parts for small batch sizes or mass production. As technology matures, AM proves to be a serious response to many common problems in the production process in companies and a real contribution to the 4th industrial revolution [4]. The integration of AM into existing production and supply networks promises great advantages for the design of customer-specific objects and thus also in the production process.

Blockchain

The blockchain (BC) is a new technology that enables all members of a network to process transactions in a decentralized, tamper-proof and transparent manner. To track the aspect of decentralization, the BC stores a series of data sets (blocks) via an individual concatenation (hash values) on its predecessor or successor data set [5].

These so-called "hash" sentences form the connection between the blocks, i.e. the chain. This creates a decentralized database with a constantly growing list of transaction data records. In many market domains, the blockchain is considered a key technology for future developments [6]. In addition to the pure storage of transactions, as e.g., featured in well-known bitcoin network, many other BC platforms such as Ethereum offer the storage and execution of so-called smart contracts (SC). These SC are computer programs that can map legal contracts and check their compliance. As a result, manufacturing companies are offered new perspectives and applications, as critical data such as design drawings or orders can be transmitted across company boundaries. Blockchain technology is able to protect the entire production chain from unauthorized access and thus increases the possibility of network cooperation [7]. Consequently, the security of product and order data can, in the near future, be handled as the strategic resource with the highest priority within companies.

Ethereum

Ethereum is a public block chain with SC functionality in which anyone can participate and contribute in mining for block verification [8]. For the validation, the proof-of-work (PoW) consensus mechanism is used, which includes a certain difficulty and requires hardware performance that leads to high power consumption [9]. For the SC functionality purpose, Ethereum, extends bitcoin's usual currency transactions by the technology of the Ethereum Virtual Machine (EVM), which enables Turing complete SC for new applications to represent business logic. The contracts are written in Solidity, which are then compiled to EVM bytecodes. To save states, each SC has its own memory. The memory represents a key value storage, with which several elementary types can be combined to complex types such as map, array and composite structures using Solidity [10]. In addition to normal currency transactions, EVM also carries out SC Bytecodes as special transactions. The hardware resources used during the execution of a contract are tracked by EVM and debited to the account of the transaction sender. If the funds of the transaction sender are not sufficient for execution, the changes are reversed by the EVM using the intermediate state changes. Since Ethereum is an open source project, the network can also be adapted as a private blockchain network to the respective needs of the application case.

Hyperledger

Hyperledger is an open source collaboration led by the Linux Foundation since 2015 and, unlike Ethereum, is a permissioned blockchain [11]. Like Ethereum, Hyperledger offers the functionality of SC, which enables the use of business logic and automation. Participants must be recognized, but not necessarily have full confidence in each other. All parties have their own copy of the distributed ledger and only see the transactions associated with their business [12]. To do tis, business partners set up a common system with a common ledger, and thereby avoid the PoW consensus mechanism [12]. Validation can only be performed by certain actuators. In addition, Hyperledger offers authorization control, unlinkable participant identity data as well as a fast and modular consensus protocol. Hyperledger therefore provides many functions that enable an application at enterprise level.

3 Architecture for a Blockchain-Based Production Network

3.1 Proposed Architecture of a Blockchain-Based Production Network

The model proposes an architecture for building a block-chain-based production network for order processing using AM. The aim is to create a structure that enables mutual interaction between manufacturer and customer. The data required for this is stored in SC in a tamper-proof and transparent manner. This data contains the address data, order data on the customer side and the address data or capacity descriptions on the producer side. A software takes over the combination of supply and demand to save the data for the order as a new SC. On the customer side, a suitable production capacity can be determined and on the producer side, customer orders can be found in order to increase the utilization of a production capacity. On the following we present a model which provides a detailed explanation of the customer's and manufacturer's point of view.

3.2 Production Order Creation Based on the Customer's Demand and Producer's Unused Production Capacity

On the customer side, the process starts based on the demand for a model to be produced. In the following, the model to be produced is referred to as a production object only. The production object is described below as a single piece, but can also be regarded as a production order with a multiple number of different models or objects. To report the demand of a manufacturing activity to the production network, the relevant production data must first be extracted from the production object as well as the manufacturing data on the customer side. For these data, a distinction must be differentiated between public and private data. The public data provides the information manufacturers need to decide whether to accept the order. Therefore, the public data include the maximum dimensions and the volume of the production object. The private data represent the digital model of the production object itself and are only stored after the producer is known and only provided to him. On the producer side, the process starts on the unused or unallocated production capacity. This requires the data of the production resource to be extracted first. In addition to the machine characteristics, the available material and the period of use, the data can also provide only a specific area within the manufacturing facility's area for the production network. This can be the case if an internal production order at the manufacturer does not use the full production capacity of a manufacturing facility. This data processing can also be carried out using an extended production planning and control system (PPC) for this application. The data processed by the customer and producer is then transferred and stored in a SC production order on the blockchain. A SC production order is created as soon as it is reported either by the customer or manufacturer. The process described in the model, which is shown in Fig. 1, only takes place when at least one customer and one manufacturer are present in the production order. If a production resource is not fully used by a single customer, other customers can also access the production resource. The SC production order is terminated when the production resource is fully used, the usable period of the production order ends or the producer ends the order. After the provision of the production resource has been terminated, the customer must first encrypt the digital model of the production object using the manufacturer's public key, from the SC production order, and then store it in a cloud storage accessible to the manufacturer. The path to the encrypted production object is then stored in the SC production order for documentation purposes and to allow the manufacturer to access the object. The producer then saves the object locally and decrypts it using his private key. Based on the production data in the SC production order and the object, the manufacturer has all relevant data to schedule, execute and complete the production order. The SC production order is completed when the customer receives his production object and records it in the SC.

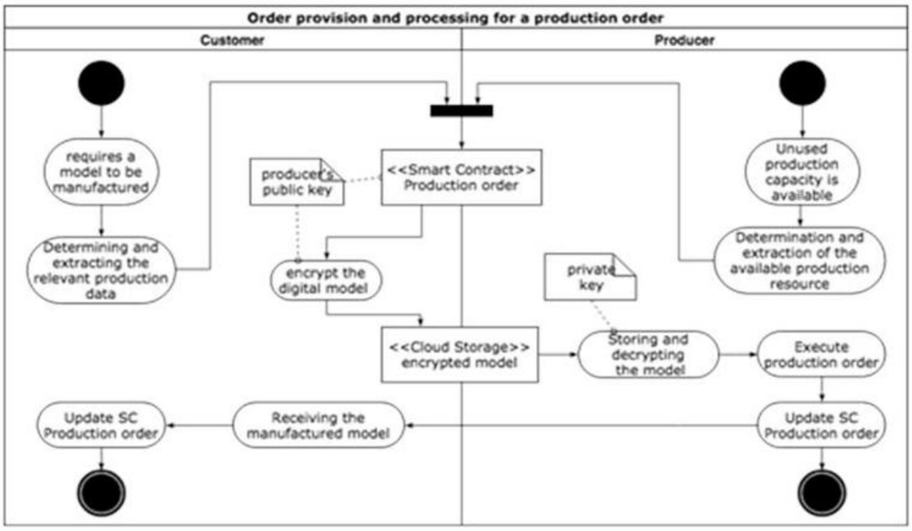

Fig. 1. Architecture of a distributed production network for order creation and processing between customer and manufacturer

4 Implementation of the Use Case of a Production Order in a Blockchain-Based Production Network

The presented architecture was validated on a public and permissioned blockchain. For this purpose, a web portal was developed that serves on the one hand for communication with the blockchain networks and on the other hand for extracting the required production data. With the portal, the roles of the customer and producer can be represented simultaneously. In this way, the stored data in the blockchain as well as in the cloud storage could be visualized. It also acts as the part of the automated data extraction from the 3D models required to schedule the necessary production resource capacities. For the public blockchain the Ethereum platform was used and for the permissioned blockchain the Hyperledger Fabric. For the experiments on the Ethereum platform, the platform was used as a private blockchain. The SC development was written for Ethereum using the language Solidity [10] and for Hyperledger the chaincode, which is the synonym in Hyperledger for an SC, the language Go was used. For the model upload of the production object for the customer, the node-stl [13] package was used for automated data extraction of the maximum object dimensions and volume. These data are required to determine the required building space on the producer side. These were then stored as SC together with further information for production. The standardized Open PGP was used to encrypt the digital model of the production model [14]. For cloud storage, a dedicated file storage server was used as central storage and IPFS [15] in the case of decentralized storage, which corresponds to the idea of the blockchain.

5 Results

The implementation has demonstrated that order provisioning and processing can be handled via the public and permissioned blockchain. With the architecture presented on the public blockchain, customers can offer their production needs to an open community of producers without the need for an intermediary in the form of a platform. Advantageous in this context is that the middleman loses data sovereignty, which allows new business contacts to be established between customers and producers. However, the resulting costs of Smart Contracts, which would represent a restriction on the basis of a public blockchain, must be taken into account. The use of Ethereum in this implementation, at this point, only represents an exemplary use of a public blockchain. Therefore, the proposed architecture could also be applied to any other public blockchain that provides the functionality of SC. In addition, the functionality of the architecture was tested on a permissioned blockchain. In case of using Hyperledger, this offers the advantage that no transaction fees are charged and the information that is made available to which participants in the blockchain can be controlled. As a result, all production orders can be processed without incurring follow-up costs on the one hand, while on the other hand creating confidence, as all parties share a common database for the orders. Furthermore, the implementations showed that there should be no doubt whether the public or private blockchain should be chosen. On the contrary, both types of the blockchain should have a justification for existence and should exist parallel to each other. Furthermore, the implementation has shown that both the public and the private blockchain have a right to exist when considering a single application case and should exist parallel to each other. In this way the public blockchain is able to establish new connections between customers and producers and to work with existing business relations the permissioned blockchain can be used to avoid further costs, while taking advantage of a mutual database. We also showed that the problem of storing large files in connection with the blockchain can be solved using cloud storage and encryption.

6 Conclusions

An architecture was presented that enables order processing between customer and producer with document exchange via a public and private blockchain. The implementation was used to examine how data can be stored in a tamper-proof and transparent manner. It was shown how production resources in a production network based on the blockchain companies can be distributed. The paper showed how production resources in a production network based on the blockchain can be distributed. Over- and under capacities, as described in the introductory part, could be managed for the producers and individual production facilities with their specific characteristics and capacities could be realized flexibly and as an integrative open production network. We also discussed that for the model of a production network public and private blockchain should exist parallel to each other. We have shown that a public and private blockchain both have a right to exist for the implementation of a production network. In this context, we also explained the possible use cases, when which blockchain type should be chosen. Further research should be done to consider the presented architecture in relation to other participants in the production chain. It would also make sense to consider the approach presented in connection with Internet of Things (IoT) in order to further automate the process flow and reduce the effort for the producer to participate.

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