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Smart Order as a new Instrument for Production Control

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Purpose: *Smart contracts are transaction programs with an "if-then logic" in relation to the blockchain technology and offer new possibilities for production control. Smart orders are derived from production orders and they are based on smart contracts. Therefore, they are created with the addition of an "intelligent" component. Basically, smart orders contribute to the ability of self-organised production systems. Blockchain-technology serves as the necessary infrastructure and, due to its properties, offers additional protection, decentralization and data security*

Methodology: *An extensive literature review is conducted to evaluate the current state of research in the area of the Smart order concept. Based on these results, a concept for the creation and use of smart orders is developed.*

Findings: *According to the literature analyses, preliminary conditions and solutions for blockchain based production control use cases are identified. Based on these findings conceptual considerations are presented for a production control system based on the use of smart orders.*

Originality: The research shows the status quo of blockchain based solutions in the area of production control. Furthermore, first results of a new production control system based on smart orders is presented. The findings demonstrate the ability of creating self-organized production systems by blockchain technology.

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1 Introduction and Motivation

Traditional centrally controlled production systems are based on extensive basic data management. Work schedules and parts lists are added to each order from the basic data management and the production process starts. If customer requirements change, a production machine breaks down or the topology of the production system changes, large-scale re-planning is necessary. Likewise, in the case of new planning or re-scheduling, there are often gaps in documentation and data security can be problematic. In today's dynamic production environment, expensive and lengthy re-planning is dangerous for a company's market position.

Companies in the aerospace or defense industry usually process on order-related basis, with the store floor organized as a workshop. The production system must be flexible enough for one-off production, but powerful enough to produce small batches economically. This scenario is prone to the problems mentioned above. To handle these problems we present the current state of our research of Smart order (SO) based production control. The SO can described as self-organizing production order that runs autonomously through the production process using smart contracts (SC). In case of a malfunction, the "smart" component becomes active and presents alternative solutions that can be selected after considering operational requirements. We aim to answer two research questions:

RQ1: How can a concept for decentralized production control using smart orders be designed?

RQ2: Is there a suitable consensus mechanism for decentral smart order based production control?

The structure of the paper is the following: Section 2 describes the methodological approach and presents the results of the structured literature review. In section 3, we give a brief insight into BCT and the features that are important for the concept. Furthermore, we define what SC are and how they work on the blockchain. The concept of the SO and the problem of validating physical measurement values in a production system is also a part of this section. Section 4 provides a more in-depth explanation of how the conversion of customer orders into production orders takes place and how the smart contracts of the SO are generated. The summary and an outlook on further research work conclude the last section.

2 Structured Literature Analysis

To identify the relevant sources, we conducted a comprehensive structured literature anaylsis (SLA). As suggested by authors Denyer and Tranfield and Hökkä et al, we use the four steps below to conduct the SLA:

Step 1: Definition of the research objects,

Step 2: Creating a framework around the research object to delineate,

Step 3: Data collection using inclusion and exclusion criteria,

Step 4: Analysis and synthesis of the research results (Denyer and Tranfield, 2009; Hökkä, Kaakinen and Pölkki, 2014).

2.1 Definition of the Research Objective

This article presents the current state of research on our smart order concept. With the SO, it should be possible to establish a self-organizing production control. In this context, the BCT serves as a secure data infrastructure and as a runtime environment for smart contracts. Smart contracts are an integral part of SO and ensure the "self-execution" of orders in the production system. In addition, when production orders are derived from smart orders, an "intelligent" component is added in the form of a production agent that takes over control in the event of deviations in the production process.

2.2 Creating the framework

Our research focuses on the development of a concept for the use of SO in production control. Previous research has shown that smart order based production control can best show its advantages in a cyber-physical system (CPS). In general, however, the logic is also applicable to partially networked production systems, where the necessary hardware and software prerequisites are available to be able to use SO in a way that increases value creation (Y. Zhang et al., 2017). The scope around the research project should be as large as possible in order not to miss any relevant sources. In doing so, we defined the terms "blockchain", "cyber-physical system" and the related terms "production" and "manufacturing". Terms such as "smart contract" were deliberately not listed in a dedicated manner, as this would lead to a narrowing of subsequent hits.

2.3 Data Collection

In order to perform a SLA according to scientific criteria, it is necessary to define databases, search criteria, keywords and other filter settings. We use the databases Web of Science (WoS) and Science Direct (SD) for our research. Both databases provide a sufficient number of hits and offer various filter settings for refining search criteria. Queries in other databases do not lead to a significant improvement of the results. As already mentioned in section 2, we follow the adapted search process of Denyer & Tranfield and Hökkä et al:

Step 1: Identification of relevant publications in the field of blockchain, cyber-physical systems in the context of production and manufacturing,

Step 2: Restriction of the results by adding further search criteria. Searched in "Computer Science", "Engineering", "Business, Management and Accounting" and in "Decision Sciences".

Step 3: Exclusion of further hits due to lack of content relevance or non-availability of the source.

Step 4: Subsequent full text analysis of the remaining publications and further reduction of the number of hits.

In the first step, the keywords were used that could be identified through preliminary research from the basic sources on the respective topic. In the first run, even more keywords were used than already noted in section 2.2. However, the use of terms such as "smart contracts" or "distributed ledger" led to a significant reduction in the number of hits. This risks that we overlook relevant publications in the field of production control related to BCT or smart contracts. The search query conducted in this way resulted in over 7,000 hits on the WoS and SD databases.

In the second step, the authors added more search criteria to focus on the actual research question. On the one hand, we wanted to find all the basic principles that would help in the development of our concept. Second, we wanted to identify and evaluate all possible research by other authors in this area. Furthermore, to the search terms, other search criteria were added and the search in the database was narrowed down to "Computer Science", "Engineering", "Business, Management and Accounting" and in "Decision Sciences". This step is necessary because SD also returns hits that have nothing to do with the research object, but our keywords were used at some point in a non-relevant article.

The third step involves the initial analysis of the title and abstract of all remaining hits. Depending on the content relevance, assigning a numerical value to the document, with a higher value corresponding to a higher content relevance. In the context of analysis, content relevance means whether the title and abstract are related to the production or production control in combination with BCT. At this point of the analysis, there are still many hits in the list of potentially usable sources, because they contain the keywords we are looking for. However, a large number of the articles have a different focus. As an example, the paper by Abbas et al. contains all the identified keywords, but has nothing to do with our research topic, but rather with the use of blockchain in the context of pharmaceutical supply chain management (Abbas et al., 2020). In contrast, 4 publications received the highest content relevance (more on content relevance in section 2.4). This does not mean that our research question is answered, but that the authors are already doing very sound research in the field of production control using BCT.

This initial analysis was performed in the literature management software Zotero. Table 1 shows the summarized research complex, technical term, and specific search terms used in the database. The * symbol can be used as a placeholder. Thus, different spellings of the same term can be included in the search.

Table 1: Identified search terms and keywords

Complex of themes	**Technical term**	**Search term / Keyword**
Blockchain Technology	Blockchain	“Blockchain*”, “Block-Chain”, Block Chain”
	Distributed Ledger	Not used
Cyber-physical System	Cyber-physical System	“Cyber-physical System*”, “Cyber physical System*”
Production/Manufacturing	Production	“production”, “product*”
	Manufacturing	“manufacturing”, “manufact*”
Smart Contract	Smart Contract	Not used
	Intelligent Contract	Not used

2.4 Analysis and Synthesis of relevant Literature

The search in both databases resulted in a hit count of 5,541. After removing 169 duplicates and 1,478 hits of none relevant research areas, 3,894 publications remained for further processing. As described in Section 2.3, we assigned the remaining hits with a numerical value. The values ranged from 1 (none content relevance) to 5 (high content relevance). Documents with a score of 1 or 2 were consequently excluded. These sources have no direct value for our research object, but show the importance of our research for other areas. The group with a value of 1 has no has no relevance to our research. However, they are still kept in our literature database because they have already been roughly analyzed. In case of a new research we can avoid additional work by automatically, removing possible duplicates of unimportant sources. Hits with a score of 3 or higher were fully analyzed. Remarkable was that four articles received a score of 5, because, to all appearances, they present decentralized production control concepts based on the blockchain. After full analysis, all four articles were downgraded to a score of 4. They have similarities with our concept, but in the final analysis, they address a different focus. The result is a set of 237 publications for detailed analysis. In the further course of the analysis, we primarily pursued the identification of prior work by other researchers in the context of SO. In the end, 59 sources form the basis for further analysis and synthesis into the smart order concept for decentralized production control. Figure 1 shows the selection process of the found literature from the scientific databases.

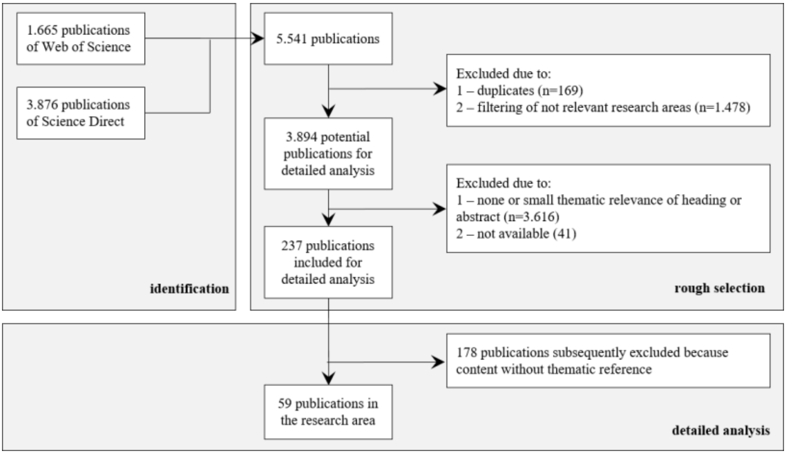

Figure 1: Selection process of relevant literature (Moher et al., 2009) (modified)

The comprehensive literature review conducted is integral to the following considerations. All relevant prior work in the field of blockchain-based production control had to be evaluated and assessed. This enabled the research gap to be clearly identified and the SO concept to be developed. However, the temporal focus was on publications between 2017 and 2021, which allowed us to guarantee that we could find all relevant recent work in the search results. At the same time, we exclude publications that are too recent. Preliminary research has shown that only from 2017 onwards BCT has been analyzed in a significant number in production.

Some researchers are already looking into the application of SC for decentralized production control. So far, there is no real use case. The team around Grey et al. use SC for the use and coordination of different agent types within a robot system. The basic idea is that agents can subcontract other agents to ensure task completion. Problematic here are the growing complexity and the possibly malicious behavior of some agents. The authors aim with their concept primarily at the extension of human abilities and less at the automated production control (Grey, Godage and Seneviratne, 2020). Li et al. focus on distributed consensus building in cyber-physical systems. Consensus building in CPS is critical, because it needs to be fast and resource efficient. To achieve this, some assumptions have been made. For example, that there are two types of nodes - active nodes and inactive nodes to save resources. What is remarkable about the work of Li et al. is that they assume changing topologies in the system. Therefore, there may be changes in the speed at which consensus is reached (Li et al., 2019). Shukla et al. go one-step further, modelling the entire CPS as a multi-agent system. They assume that every object in the CPS acts as an agent. As mentioned in Li et al. they also use BCT to implement SC. The introduction of SC in the multi-agent system is to prevent harmful behaviour of the agents and thus enable distributed plan execution (Shukla, Mohalik and Badrinath, 2018).

3 Blockchain-Technology in Production Control

3.1 Origin of Blockchain-Technology

In 2008, the end of the financial crisis raised many questions about the functioning and safety of financial institutions, such as banks or other financial service providers. When the bubble burst in the U.S. real estate market, many of affected people did not have the opportunity to react appropriately to the market movements. One of the main reasons was information asymmetries between the financial institutions and investors (Schinckus, 2020). As a result, the pseudonym Satoshi Nakamoto postulated the Bitcoin Whitepaper. Instead of an account at a bank, users are supposed to create "digital addresses" on a decentralized network, the blockchain. Instead of FIAT money, cryptocurrencies can be sent from one address to another without relying on a central entity, such as a bank (Nakamoto, 2009).

However, currently common payment systems such as SEPA or payment service providers such as Klarna or PayPal use a central node in form of a bank. The bank, as the intermediary, therefore has more control over the transaction than the parties involved do. In addition, the rules and conditions can be influenced or even changed by the central node. Furthermore, an attack on the central node in the network can cause severe damage and lead to a loss of trust among all network participants. This means that even after restarting, the network can suffer permanent damage (Yli-Huumo et al., 2016). In contrast, the blockchain structure corresponds to a decentralized database. In an open blockchain, everyone has the opportunity to participate in the network and execute transactions. In case of being an active node, you download a complete version of the blockchain to your local hardware. You are also authorized to validate transactions and create blocks yourself if you have sufficient computing power. In the Bitcoin blockchain, this is the mining process (Christidis and Devetsikiotis, 2016; Skowronski, 2019; Berneis, Bartsch and Winkler, 2021).

The best-known use case of BCT is the cryptocurrency Bitcoin. With a price of almost 67,000 U.S. dollars in November 2021, bitcoin again became increasingly popular (coinmarketcap, 2022). Therefore, the BCT also increasingly attracting the interest of industry and research. Chapter 3.2 describes the general structure and explains the most important features.

3.2 Structure of Blockchain-Technology

The name blockchain is derived from the way information is stored (see Figure 2). It does not matter what kind of information is stored. On the Bitcoin blockchain, transaction data is stored, but on other blockchains, it is also possible to store images or video files. The Genesis block is the first block of a blockchain and is created via software or the personal preferences of the blockchain's creator (Christidis and Devetsikiotis, 2016; Christidis et al., 2021).

A blockchain is decentralized, which means there is no central entity and no third party that can change the rules or conditions without the agreement of the participants. A blockchain-based network consists of nodes, each of which has a complete version of the blockchain on its local hardware. Consensus is required to change rules or confirm transactions. In the Bitcoin blockchain, the consensus mechanism is the so-called Proof of Work (PoW) (Schinckus, 2020). At this point, it should only be noted that there are a variety of consensus mechanisms that can be chosen according to the later use case (Hazari and Mahmoud, 2019; Liu et al., 2019; Berneis and Winkler, 2021). Because our research objective is production control using BCT, PoW is not suitable due to the resources required.

Each block consists of a unique hash value, a transaction list, and other information such as a timestamp or the nonce. The block header contains the hash value of the previous block. This creates a concatenation that makes the blockchain longer and longer. This ensures that it is almost impossible to change the data stored. If someone tries to change the data in one block, the entire blockchain must be changed from the block in which the change is made (see figure 1) (Z. Zheng et al., 2017; Alphonse and Starvin, 2020; Christidis et al., 2021).

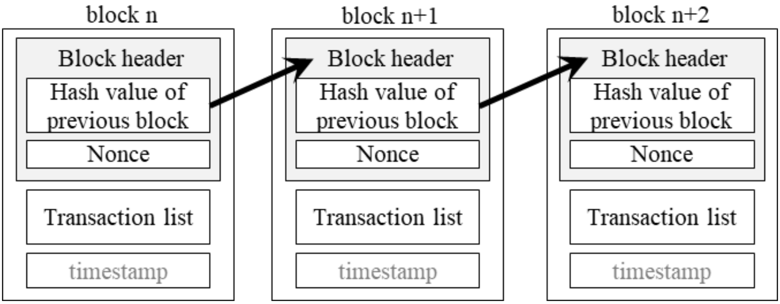

Figure 2: exemplary blockchain structure (Rathore, Mohamed and Guizani, 2020) (modified)

3.3 Key features Blockchain-Technology

The decentralization and the linkage of blocks building the structural basis for the key properties of BCT, which makes it so interesting for many applications. Every blockchain is based on distributed ledger technology (DLT), which means that the ledger is completely shared and updated by all participants. Thus, a blockchain-based solution is secure and transparent. Additionally, the data in a blockchain is immutable. Using the Bitcoin Blockchain as an example, changes could only be made if one party had more than 51% of the computing power of all participants at its disposal. Due to the size of the Bitcoin blockchain, this scenario seems very unlikely (Iansiti and Lakhani, 2017; Schinckus, 2020). Research in the context of cyber-physical production systems (CPPS) shows further advantages of BCT. Adding new participants to the production system is quickly and securely. It is also possible to assign a losable stake to each participant and thus implement sanction mechanisms physically as well as in the cyber layer (Skowronski, 2019).

In summary, it can stated that a PoW based Blockchain is a decentralized, transparent and immutable database and thus offers a high degree of security. Any type of data or information can be stored in concatenated form. It works without a central entity and has no central point for attacks from outside.

3.4 Smart Contracts

Nick Szabo is the father of smart contracts. Vitalik Buterin, the founder of Ethereum, uses the fundamental research and defines smart contracts as a code or data that represents a business logic and runs on a blockchain with a specific address (Szabo, 1997; Buterin, 2014). Ante describes the smart contract as a script that is stored on the blockchain and uses it as a runtime environment. Just as the transactions are visible, the conditions in the smart contract are also visible to all parties involved. Therefore, trust between the parties is not necessary and yet the respective interests of the contracting parties are protected to the maximum. Smart contracts operate based on mutually assured terms and require a trigger event to execute the next step. Without a trigger, such as a transaction, the SC does not become active (Ante, 2021).

Primarily SC are used for automated payment processing between two or more parties. They are electronic transaction protocols that run on the blockchain and thus have properties such as the immutability of the code. The main components of SC are the mutually assured agreements, contract data and the expiry routine in the code (Baygin, Baygin and Karakose, 2020; Ante, 2021).

3.5 Smart Order as Instrument for Production Control

Modern fully connected production systems have to control a multitude of machines, conveyor vehicles, but also human personnel. Often, this task is carried out by a central unit and results in the order processing process. In the classic order fulfilment process, a central point receives the customer order. The customer order is then enriched with further information, e.g. materials from external sources, and forwarded to the appropriate areas (Schuh and Stich, 2012). All sales orders in total and demand forecasts form the basis for production program planning, quantity planning and the planning of required capacities. After release, the sales orders become production or purchase orders. Now it is the task of the production control to carry out the machine occupancy planning based on the detailed scheduling. Evaluating of deviations in the production process because of a continuous actual-target comparison (Kellner, Lienland and

Lukesch, 2020). The concept we will present starts with production control, i.e. detailed scheduling and the associated machine assignment planning.

We propagate the smart order as an innovative concept for the self-organization and self-execution of customer orders. Smart orders are derived from the respective customer order. The process begins when the customer places the customer order. This can be done via various channels, e.g. an account integrated into the blockchain. Already through the login, various information is available that was stored in the database through the previous customer account creation. The customer order contains all the information needed to create the production order, such as order items, quantities, deadlines or special conditions, such as packaging requirements. The customer-specific information is supplemented with the data from the basic data management. Required routings (in-house production or external procurement) and parts list information are added. Now, the system assembles the SO by automatic generated SC, which have been programmed in advance and are tailored to the respective product. The SC are generic in that the source code is automatically adapted based on the order data. For example, quantities, deadlines or special conditions are automatically recorded by customer input and implemented at the appropriate points in the SC. In addition, a distinction is made between parts from in-house production and purchased parts (see Figure 3). This means that only the information required for execution is stored in the SC. This makes the SC more secure and reduces complexity. In practice, overly complex SC lead to execution and comprehension problems (Garamvolgyi et al., 2018; Ante, 2021). This procedure is performed for each order item. The approaches from Section 3.4 use agents to execute production control, which leads to the problems already mentioned. We execute production control using the “if-then logic” of smart contracts. The production agent of the SO primarily has an inactive observer status. If an unanticipated incident occurs, such as a machine failure, the status will be changed to active. The core task of the manufacturing agent is to present solutions. He can check whether another machine is suitable for the upcoming operation and search for free capacities.

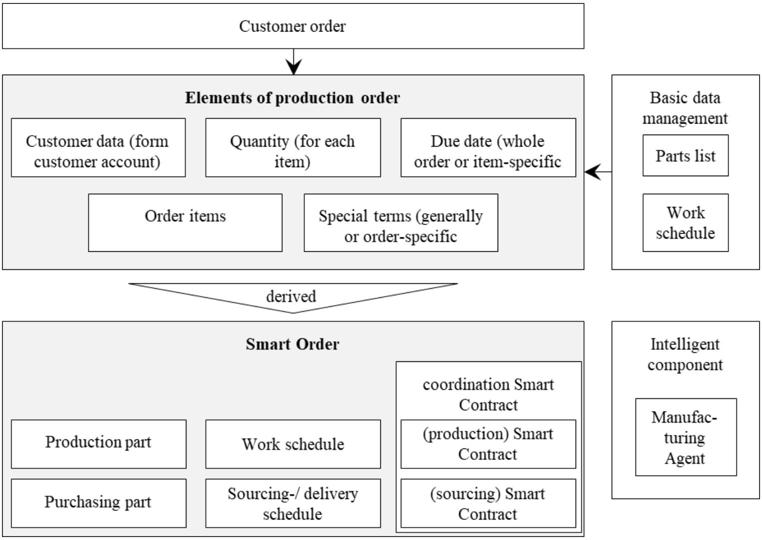

Figure 3: Derivation of the smart order from the sales order for one order item

3.6 What to validate?

A consensus mechanism is required to validate the data to be stored or to change the system status. Since the blockchain has a decentralized structure, the participants must find a consensus (Kobzan et al., 2018; Hazari and Mahmoud, 2019). Due to the growing number of blockchain-based applications, various consensus mechanisms have evolved. The best known is the Proof of Work (PoW) for validating transactions in the Bitcoin blockchain. The PoW is not only used for verifying and validating transactions, but also for creating new Bitcoins, called mining. To create a new block, the miner has to solve a cryptographic puzzle. The other nodes can confirm the solution very quickly. If there is a sufficient match, the block is appended to the blockchain and the successful miner receives a reward in the form of Bitcoin. Criticism of PoW arises from the high energy consumption required to solve the puzzle (Xu et al., 2017; Kobzan et al., 2018; Hazari and Mahmoud, 2019; Xu, Chen and Kou, 2019).

So far, most consensus mechanisms arise from applications in the fields of finance and cryptocurrencies. For new applications, e.g. in the area of supply chain management, these are modified or fulfill their task without adaptations (Decker, Seidel and Wattenhofer, 2016; Kraft, 2016; Z. Zheng et al., 2017). The work already presented in section 3.4 also uses the paradigm of validating transaction data. From our point of view, it is questionable to validate only transaction data in a production system that manufactures physical products. We would only determine that the correct data capturing and that the process execution is correct according to the SO. However, we do not know if the physical characteristics of the product, such as length or weight, are as specified. Deviations from the desired product properties can occur, for example, because incorrect calibrated or externally compromised machine.

In CPPS, information flows trigger the corresponding material flows, i.e. after order release, making the raw material available at the workstation by an autonomous transport system. The release and the individual transport steps already represent trigger events for the smart contracts in the smart order. This automates the process. After the processing operation on the workstation, the component is subjected to a quality inspection. The inspection is performed independently of the workstation to prevent false positives. The inspection can be performed with simple optical or mechanical devices. The inspection information is transmitted and analyzed via the sensor technology, e.g. via RFID, of the inspection equipment and, if it matches the target values, it is entered as data in the next free block and validated by the network. As soon as the validation has been published in the network, the SC of the smart order is triggered again and the next processing step can start. This ensures complete and secure traceability of the information and material flow.

The analysis of the properties of the different consensus mechanisms show that they are only suitable to a limited extent or not at all for use in the SO based concept for production control. Table 2 shows the comparison of three available consensus mechanisms that may be suitable for use in blockchain-based production systems. For example, PoW is not listed because it is neither scalable nor resource-efficient (Hazari and Mahmoud, 2019). They only require the available computational power that is already in the CPS, but the process for reaching consensus is not ideal for all three mechanisms.

Table 2: Comparison of possible production consensus mechanisms (Nandwani, Gupta and Thakur, 2019; Manolache, Manolache and Tapus, 2022; Singh et al., 2022)

Consensus mechanism	**Proof of Participation**	**Proof of Authority**	**Proof of Importance**
Election of block-creator	Height of participation level	Reputation level instead of assets	Importance for the entire network
Registration of nodes	Yes, incl. testing according to specified rules	Yes, preference is given to nodes that have been verified	No, fake accounts are possible
Decentralization	Partly	Partly	Partly
Energy consumption	Reduced*	Reduced*	Reduced*
Computing power	Reduced*	Reduced*	Reduced*
Motivation for block-creation	Block-reward	Increase of reputation level	Block-reward

*Compared to Proof of Work (PoW)

During the development of a Proof of Quality (PoQ), the measurement data of the physical measurement is recorded by a separate measuring point and presented to the network. If the measurement data from the production station and the measuring point match the target values from the design and construction documents, these are validated by the network participants. The PoQ is currently under development.

4 The Process of Smart Order Creation

In this following chapter, we will go into the required (pre)services that the production system must provide in order to be able to use the SO. First, we provide a brief insight into the process of creating a production order by means of a customer order. Then, we briefly outline the general process for creating the SO, including the generation of the required smart contracts.

4.1 Creation of the Production Orders

The concept of the smart order aims to productions with reference to customer orders. Because of this reference, an inspection process is consequently initiated with each sales order. This includes the classic tasks of production planning and control (PPC), i.e. production program planning, quantity planning, scheduling and capacity planning. The order is released when all planning tasks have been completed positively. To avoid overloads in the production system, scheduling and capacity constraints are used to ensure a workload-oriented order release (Schuh and Stich, 2012; Lödding, 2016). The customer logs in via a verified account and already provides the first information through his login. He now selects the products he wants. A new order item is created for each product. Likewise, the delivery date and the desired quantities are recorded. By adding other conditions, the customer completes his order. In the simplest case, there is no production order with this order item in the production system and the customer has selected just one order item (see Figure 4).

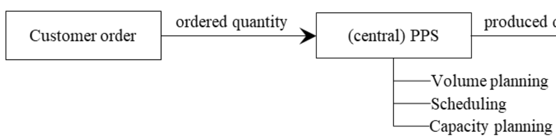

Figure 4: Production order equals to the sales order (Lödding, 2016)(modified)

In business operations, other variants of sales orders occur. First, a sales order often has more than one order item, meaning that a sales order triggers more than one production order (see Figure 5).

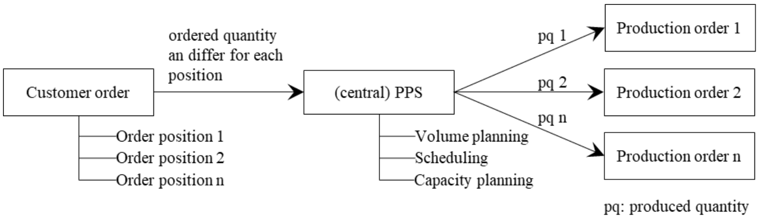

Figure 5: Sales order generates multiple production orders (Lödding, 2016)(modified)

On the other hand, it can also happen in order-related production that several customers order the same product. In this scenario, it makes sense to combine the various similar order items into one lot (see Figure 6).

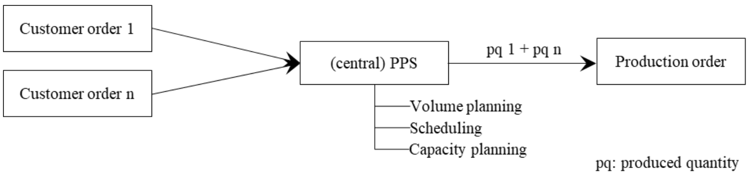

Figure 6: several similar sales orders are combined into one production order (Lödding, 2016)(modified)

4.2 Smart Contracts as Core Element of Smart Orders

The creation of the SO forms the transition from the centralized to the decentralized paradigm of the concept presented. The smart contracts are the mainpart of each SO. For each production order, all necessary SC are tailor-made. The smart contracts are created generically and automatically for each product. Care must be taken to maintain a uniform standard for the master data. In this way, the respective code components can be inserted in the correct places in the SC template using an algorithm. The smart order contains several smart contracts. On the one hand, there is the production-SC. This contains all the information from the work plan, i.e. the technological sequence of the work steps and process instructions. At this point, we assume (partially) flexible work plans, i.e., under certain circumstances, other sequences can be used for machining (first grinding, then drilling) or manufacturing technologies can be substituted (waterjet cutting instead of laser cutting). This increases flexibility in the CPPS. Using the “if-then” logic of smart contracts, automated queries can be made regarding alternative routes through production. The sourcing-SC contains the procurement or delivery plan. The information needed for automated order execution comes from the bill of materials and any inventory query. Both SCs are in mutual exchange of information. The higher-level Coordination smart contract is responsible for the correct assembly of the production order into the finished sales order.

Smart contracts offer versatile applications in the production context due to their very good customizability. Due to the complexity of the source code, they also carry risks, such as incorrect execution of work plans or transactions (Hewa, Ylianttila and Liyanage, 2021; Omar et al., 2021) We therefore envision designing a template and having the missing code automatically filled in. Each SC has a unique hash value and an action list. This list in turn contains the specific information from the basic data management. Once a step has been completed and validated by the network, the SC recognizes this trigger event and continues as scheduled. If it is not possible to continue according to plan, the SC contains a routine for calling the production agent. This agent checks autonomously and by communicating with other active agents what options exist for rectifying the problem. Once the SC and thus the production order has been processed, the completion routine is initialized. The coordination smart contract now checks whether the other production SCs, if any, are ready and initiates the assembly or the compilation of the order for the customer.

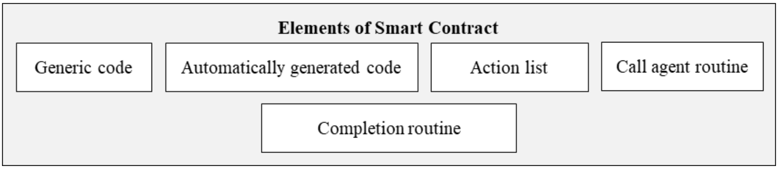

Figure 7: Basic parts of smart contracts for building smart orders

4.3 Advantages caused by Smart Order Utilization

We recommend implementation in a cyber-physical production system in order to fully exploit the potential of the concept presented. Production control through smart orders requires resources that are only available in their manifestation in a CPS. CPS are production systems that have a physical and a cyber-component. Both dimensions influence behavior equally. At the core of CPS are embedded computer systems and networks. These are fed information from sensors in the physical world, process it, and reflect it in the form of actions in the physical world. Comprehensive actuator technology, such as a robot, is necessary for implementation (Lee and Seshia, 2017; Barenji et al., 2020).

With the introduction of SO based production control, we expect direct and indirect improvements. The transition from the centralized to the decentralized paradigm will increase the flexibility of the production system as a whole. The (partially) flexible work schedules of SO will increase the flexibility in individual areas through the possibility of re-routing. Therefore, machine utilization will increase and we will get measurable cost and lead time reductions. Compared to classical production systems, a reduced number of human interventions can be assumed. In the event of a malfunction, the SO's production agent should independently develop and present proposed solutions. The personnel finally make the selection of the measures.

The indirect improvements can only be evaluated with a real application. Nevertheless, we assume that the needs of some industries will be satisfied significantly better (see section 1). The increase in resistance to unauthorized access, especially from outside, is noteworthy. The use of BCT already leads to an increase in security due to its technological features (see sections 3.2 and 3.3) (Bartsch and Winkler, 2020). Additionally, real production data is recorded through external measurement and validated by the PoQ. If an attacker wants to compromise a machine, it is no longer sufficient to attack only the machine, but also the measuring station.

5 Conclusion and Outlook

To answer the first research question, we have presented initial considerations for decentralized production control using the smart order concept. The required SC are generated automatically and are composed of various modules. For the most efficient use of machine capacities, (partially) flexible work schedules are used, which allow switching to other production technologies or changing the work steps. In contrast to the approaches in the literature, the concept refrains from the active use of agents in normal operations. The use of agents is primarily limited to passive observation of the production process. This reduces the complexity of the system and excludes harmful behaviour of agents. In the case of a deviation from normal operation that cannot be solved by the SC, the status of the agents is set to active. This is to present proposed solutions using historical data and the analyses from the observations. The solutions are then discussed by the staff and either accepted or rejected.

The aim is to map and simulate the concept in a suitable simulation model. Production data with a classic centrally controlled production and a production controlled by the smart order concept are to be compared with each other. There is a need for further research:

- A uniform standard and a mechanism for the completeness and correctness of the basic data must be found. Since this data will later be automatically integrated into the smart contracts, major disruptions in the production process are to be expected if the basic data is incorrect.
- Based on this, a suitable template for the smart contracts must be found, tested and verified.

The second research question about a suitable consensus mechanism cannot be answered conclusively. For a target-oriented simulation with realistic latency times and data transmission rates we are currently developing the Proof of Quality. Initial approaches for a PoQ are already available. The data from the machine-independent measurements will be validated.

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