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INDUSTRIAL APPLICATION OF BLOCKCHAIN TECHNOLOGY – ERASING THE WEAKNESSES OF VENDOR MANAGED INVENTORY

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Research paper

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Abstract

Technological advancements, such as machine learning or the concept of blockchain, have the potential to reshape entire branches of industry as a disruptive technology, but also offer the possibility to optimize existing processes. In this paper, we present a concept for vendor managed inventory relationships based on blockchain technology. Hence, we initially define necessary processes and transactions that highlight a special need for transparency and trust between the participants. We designed and developed a proof of concept that addresses the weaknesses of current VMI solutions by performing certain process steps in the blockchain. Thus, we implement a method based on smart contracts, which can interact with existing systems by using different data interfaces and therefore represents an application of Blockchain 3.0. The present work is intended to explain the concept to the reader and to support researchers for the future development of further industrial applications of the blockchain.

Keywords: Vendor Managed Inventory, Distributed Ledgers, Blockchain 3.0, Supply Chain, Industrial Blockchain Application.

1 Introduction

Blockchain technology offers a form of transparency and security with its concept of decentralized data storage in combination with the implemented consensus mechanism and the cryptographic protocol in general (Hellingrath & Kuhn, 2013; Notheisen et al., 2017), and therefore raises considerable opportunities for all industries. After the first blockchain was implemented with Bitcoin in 2009 (Beck et al., 2016; Nakamoto, 2008), the focus of attention in the financial sector increased (Rückeshäuser et al., 2017). The Bitcoin blockchain was originally started with the purpose of being an alternative mechanism for building trust in payment transactions (Holotiuk et al., 2017). The blockchain substitutes were especially trusted for the transparent nature of the design, thus freeing users from the necessity of implementing trust mechanisms or interacting with intermediaries (Beck et al., 2016; Rückeshäuser et al., 2017).

Due to its great potential, awareness is also continuously increasing among other sectors (Holotiuk et al., 2017). In contrast to rather widespread applications in the financial industry, the paper at hand presents a possible industrial use case of this technology in the area of supply chain management. Because blockchain offers the possibility to track all types of transactions securely, reliably and transparently, there seems to be great potential in the adaption of technology in this field, because trust is considered as a particularly critical success factor (Kwon and Suh, 2004). The concept of vendor managed inventory (VMI) a partnership-based cooperation represents a special form of supply chain management. Despite the widely explored and described advantages that VMI offers over conventional forms of replenishment (Claassen et al., 2008; Sari, 2007), this concept is in fact still not well established in the broad spectrum of corporate practice (Hammer and Bernasconi, 2016). Two of the main obstacles to this concept are the necessary high initial investments and the need for trust between the business partners involved, e.g., regarding to the provision of the correct planning data (Hammer and Bernasconi, 2016; Vigtil, 2007). In contrast, in a blockchain-based VMI concept the blockchain ensures each process step is recorded in a tamper-proof manner (Beck et al., 2016; Zyskind et al., 2015), which enhances reliability and transparency (Düring and Fisbeck, 2017) and therefore, confirms the fitting accuracy of this concept to deal with the weaknesses of vendor managed inventory relationships. Furthermore, all generated data or related references are located in a decentralized and verifiable blockchain platform instead of data silos, which are often created based on integrated enterprise software of the participating companies (Düring and Fisbeck, 2017) and could reduce otherwise required investments to connect the data silos via the implementation of individual interfaces. We summarize our research questions as follows:

(1) *How can a blockchain-based VMI relationship offer benefits over and deal with the weaknesses of traditional implementations of VMI?*

(2) *How can blockchain applications be implemented into enterprise operations utilizing the concept of VMI as an example?*

2 Methodology

To answer our research questions we used a design science research (DSR) approach, which has advantages over other research methods (Gregor and Hevner, 2013; Hevner et al., 2004) and has been used in similar papers (Beck et al., 2016; Nærland et al., 2017). In general, DSR is intended to create something new to solve an existing problem (Gregor and Hevner, 2013; March and Smith, 1995). There are four main types of possible contributions of the DSR approach in particular constructs, models, methods and instantiations (Gregor and Hevner, 2013; Winter, 2008). Considering their characteristics and degrees of generalization, as well as our intended knowledge contribution, we decided to create a set of techniques forming a method describing a blockchain-based VMI concept as postulated by Gregor and Hevner (2013) and Winter (2008). More precisely, in our contribution the shortcomings of VMI should be reduced and the established concept of a supplier-controlled warehouse shall be improved using new technology, such as blockchain, in order to generate further advantages to the stakeholders of this logistics concept.

The DSR process consists of six iterative steps: (1) identification of the problem, (2) definition of the artefact, (3) design and development of the artefact, (4) demonstration, (5) evaluation, and (6) communication (Peffers et al., 2007). The research process starts with the identification of a suitable and relevant problem (1) (Hevner et al., 2004; Peffers et al., 2007). In this paper, potential possibilities of blockchain technology, were considered. Results from a qualitative study and a systematic literature review suggest a huge potential for blockchain technology in processes that are strongly influenced by transactions and contain a significant trust component. VMI as part of the supply chain is an established method for optimizing warehouse concepts, but in practice it has not become very popular (Lee and Whang, 2000) and is therefore to be investigated. So, some background information about blockchain and vendor managed inventory is presented in chapters 3 and 4, which leads to the problem description (1). The definition and design and development of the created method are presented in chapter 5 (2, 3), followed by an evaluation of the method by implementing and testing a prototype in our ERP research laboratory (4, 5). The communication of our method takes place in this article (6).

3 Increasing transparency of transactions in distributed ledgers

If transactions are processed directly via digital methods, it is almost impossible to provide unchangeable and unequivocal proof so far. Therefore, intermediaries are required to verify and document a transaction. Trusted third parties, such as institutions like banks or governmental organizations, benefit from a traditional advance in trust and can reduce the mutual trust of transaction parties. However, this service causes high transaction costs and does not guarantee data security or integrity of the data (Bravo et al., 2015; Tapscott and Tapscott, 2016).

In contrast to today's concepts, blockchain relies on distributed and thus decentralized data storage in several nodes. Therefore, there are digital decentralized ledgers in which each transaction is stored redundantly and distributed to all nodes involved (Glaser and Bezzenberger, 2015; Nakamoto, 2008). Several transactions are combined in a so-called block which contains an additional reference to the previous block to create a fixed chain of blocks. The exact cryptographic method for generating the blocks depends on the blockchain protocol used in a particular application (Beck et al., 2016; Glaser and Bezzenberger, 2015). The referencing process creates a chain that ensures the traceability and integrity of all stored transactions from today to the beginning (Nakamoto, 2008).

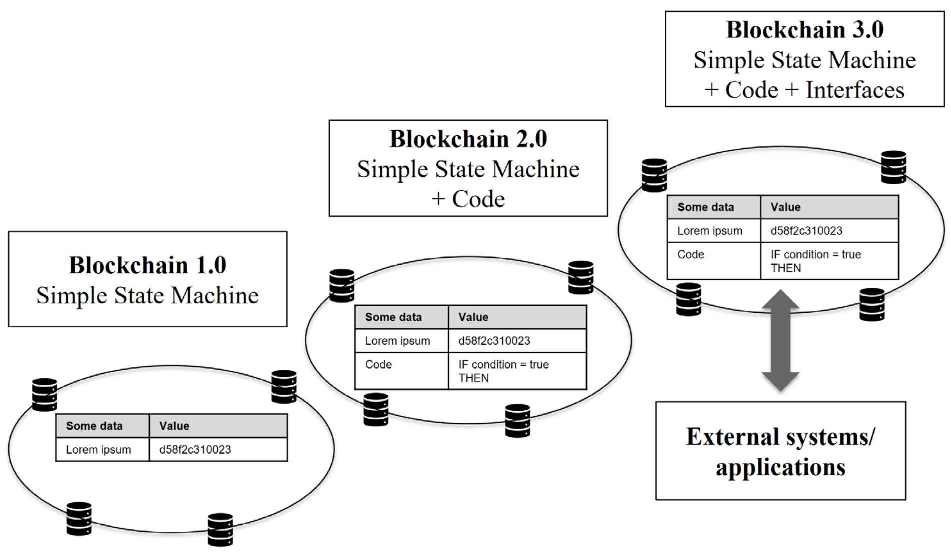

Figure 1: The evolution of the blockchain technology

Since the concept of Nakamoto (Nakamoto, 2008), the available blockchain protocols have undergone rapid development and can be distinguished into generations based on fundamental differences in functional range and mode of operation, similar to the distinction between Web 1.0-3.0 (Barassi and Treré, n.d.; Fuchs et al., 2010) (see Figure 1). While rudimentary protocols, such as the Bitcoin Blockchain, correspond to a simple state machine and represent only an alternative payment method (Blockchain 1.0), the following protocols are equipped with more extensive functions. Protocols such as Ethereum and Lisk also offer the simple documentation of transactions and the possibility to execute source code directly within the protocol (Blockchain 2.0) (Sixt, 2017; Swan, 2015). So-called smart contracts allow, for example, the time or event-based automatic execution of transactions and can communicate with other programs (Buterin, 2014; Szabo, 1997). If smart contracts are extended by an interface to other external systems, such as ERP systems, smart devices, or human interaction interfaces, the term Blockchain 3.0 can be used (Dörner, n.d.; Swan, 2015). Such software solutions are called decentralized applications (short DApp) and describe the decentralized execution of applications (5chdn, 2016; Buterin, 2014).

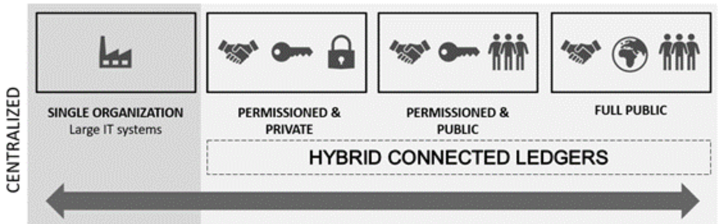

Figure 2: Different types of access to the blockchain network

The access to the blockchain network varies depending on its configuration, which can be divided into three different settings as illustrated in Figure 2. A basic distinction is made between public and private blockchains (Beck and Müller-Bloch, 2017; Nærland et al., 2017; Pilkington, 2015). Differences occur from the following questions: who has access to the network, who can execute the consensus mechanism or smart contracts, and who can store and process an instance of the data called node? A public blockchain (full public) is open to every potential network participant and typically provides incentives to encourage participants to join the network (Buterin, 2015). In the public Bitcoin blockchain, for example, this is represented by mining rewards in the form of Bitcoins. In contrast, for access to a private blockchain (permissioned and private), an invitation or key is required to perform certain actions. The author of the private network determines the configuration of the authorized network and the access barriers by means of a set of defined rules. For example, an invitation can be issued centrally by the author, a regulatory body, or (authorized) members of the network (Buterin, 2015). Previous large IT systems were usually located within a single organization and therefore represent an early form of a private network. If a private blockchain is controlled and used by a larger and pre-selected group of participants (permissioned and public), it can also be called a consortium blockchain (Buterin, 2015; Underwood, 2016; Xu et al., 2016). In the following, we will show how the presented technical methods of the blockchain technology can be deployed in practical applications using our VMI method as an example.

4 Processes and transactions of vendor managed inventory relationships

The major distinction between the concept of buyer managed inventory and VMI is right at the beginning of the process. In the classic procurement process, a customer triggers the purchase order and transfers the parameters determined by himself, such as delivery quantity, quality, and place of delivery, to his supplier. With VMI, the buyer evades this responsibility and transfers it to the supplier. For this purpose, the supplier is provided with all agreed information (see Figure 3), which is necessary for inventory and delivery management (Werners and Thorn, 2002).

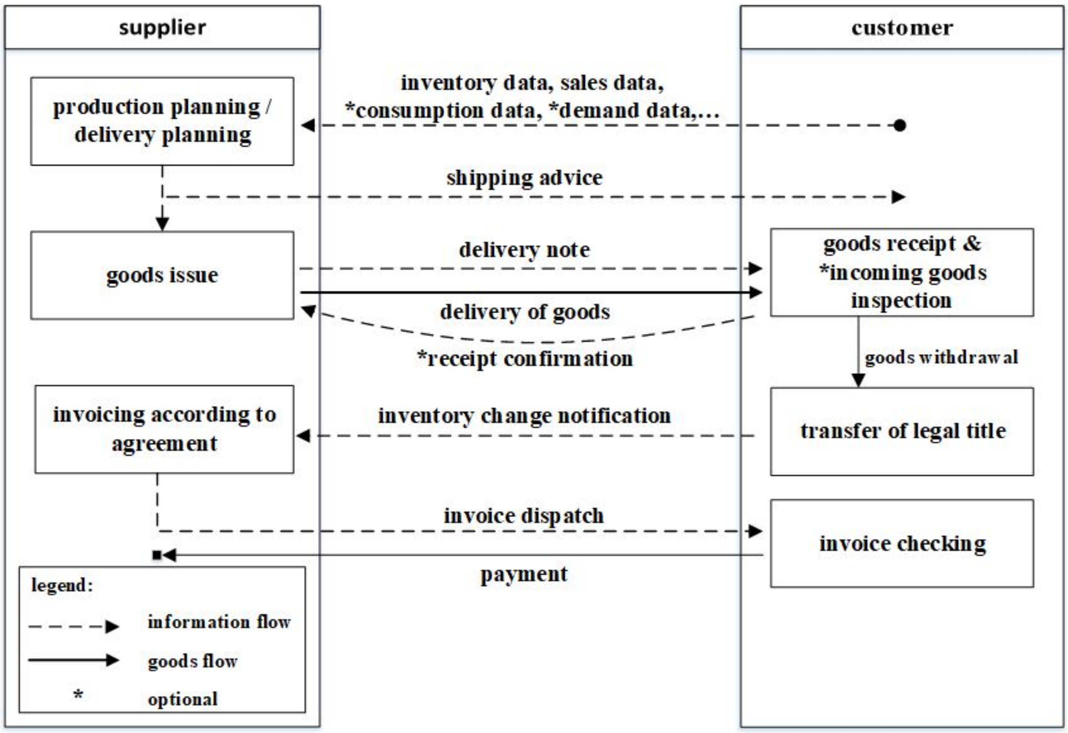

Figure 3: Transactions in a simple VMI partnership

The exchanged information particularly includes inventory data, consumption data, sales data (like received orders), and may also include other data such as production plans and planned marketing campaigns, depending on the intensity of the partnership (Vigtil, 2007). The data originates from the customer's information systems, primarily integrated enterprise resource planning (ERP) systems that enable electronic data exchange by interfaces, for example via EDI or XML technology (Neuß et al., 2017; Vigtil, 2007). Through this the transmission time and input errors can be kept to a minimum.

Using the data transmitted, the supplier can carry out delivery planning and thus determine the optimum delivery and production batch sizes (Werners and Thorn, 2002). The regular subsequent decisions on the delivery quantity, shipment, and scheduling form the basis for the individual deliveries. As soon as the delivery leaves the supplier's warehouse, the customer can be informed of the upcoming delivery via a shipping advice (Waller et al., 1999).

The received goods are stored at the buyer's warehouse and usually remain the possession of the supplier for the time being there. The transfer of the legal title to the buyer does not take place until a previously contractually defined point (Alicke, 2005) and may be detached from the passing of possession. It can take place at different points in time along the process chain. Thereby, the transfer of ownership can already take place upon delivery of the goods or, as shown in the illustration, upon removal of the goods from the warehouse (Vigtil, 2007). The goods will only be offset with the transfer of the legal title of the goods (Alicke, 2005). The specified contract conditions determine the time delay for the invoice dispatch (Ståhl Elvander et al., 2007; Vigtil, 2007). For the purpose of invoice bundling, for example, monthly payments can be agreed upon (Vigtil, 2007) or an exact piece-by-piece immediate settlement can be carried out (Ståhl Elvander et al., 2007).

Requirements for a VMI concept are multifarious. For example, trustable information exchange is essential for procurement management, since different and especially correct data is required at different times (Vigtil, 2007). Furthermore, technical support, such as the use of an information system for data acquisition and the use of an interface for electronic data exchange, is of great importance (Tyan and Wee, 2003). Collaborations along the supply chain require mutual trust, as internal processes are transferred to an external partner. For a successful VMI partnership, secure access to confidential information must be guaranteed and the risk of faulty deliveries or even out-of-stock situations must be kept to a minimum. However, contracts and financial incentives or penalties can only replace this trust, which is intended to substitute the loss of control over outsourced processes, to a certain extent (Vigtil, 2007). In the following taxonomy (see Table 1) the requirements of the VMI were deduced from the literature and compared to the individual process steps of the replenishment process, which must be considered for the design of the IT artifact. This is intended to concisely summarize the steps in which data are generated or required and thus gives an impression of the complexity of this concept. The hereby identified characteristics are also required in chapter 5 to design the blockchain-based VMI. Therefore, the relationship between the partners is decisive for a successful VMI cooperation (Hammer and Bernasconi, 2016). In addition to cost and risk factors or product characteristics, obstacles, and reasons for the failure of VMI, implementations are generally found in the processes of communication and information exchange between the parties. In particular, the lacking willingness to share data often hampers the implementation of VMI (Kuk, 2004; Vigtil, 2007). This is mainly due to a lack of mutual trust (Sari, 2007).

	Processes of VMI											
Requirements of VMI	Delivery planning	Gods issue	Shipping advice	Delivery of goods	Goods receipt	Receipt confirmation	Goods withdrawal	Inventory change notification	Invoicing	Invoice dispatch	Invoice checking	Payment
Integrated IT systems	x	x	x		x	x	x	x	x	x	x	x
Electronic data exchange			x			x		x		x		x
Trust on the supplier side					x	x	x	x			x	x
Trust on the buyer side	x	x	x	x					x	x		x
Information exchange												
Inventory data	x							x				
Sales data	x							x	x			
Consumption data	x							x	x			
Demand data	x											
Marketing activities	x											
Delivery data			x	x	x	x						
Settlement data								x	x	x	x	x
Product data	x	x			x	x	x	x				
Quality and consistency of data	x	x	x		x	x		x	x	x	x	x

Table 1: Taxonomy of the requirements for VMI processes

Up to now, all data of the supplier and the buyer have been stored in their ERP-system-based data silos, which only allow limited communication with each other because external parties do not typically have access (Düring and Fisbeck, 2017). Both partners collect and control their data themselves. In general, centralized systems can be seen as more error-prone than distributed ledgers and offer more efficient ways for manipulation (Düring and Fisbeck, 2017). In order to achieve permanent transparency, a complete and unchangeable history is required (Düring and Fisbeck, 2017). In the blockchain, each process step and each transaction can be documented in a tamper-proof manner and stored data can be exchanged decentral (Düring and Fisbeck, 2017), which can solve this problem. Confidence in statements of the other contracting party is therefore not considered to be meaningful, as it can be proven by reliable knowledge (Düring and Fisbeck, 2017). Blockchain is a suitable instrument for eliminating concerns about the lack of mutual trust between the partners (Beck et al., 2016), e.g., like those involved in a VMI relationship, which highlights the accuracy of fit of this solution approach. Shifting important processes to a distributed ledger leads to increased transparency and can raise the performance of VMI collaboration. Therefore, our detailed method of a blockchain-based VMI is presented below.

5 Vendor managed inventory based on blockchain technology

5.1 Design of a decentralized VMI platform

The IT artifact of this paper represents a method for a blockchain-based VMI concept, following the taxonomy presented in Table 1, with a central blockchain as a platform between two to *n* parties and their information systems (see Figure 4). The blockchain network consists of the decentralized server nodes and includes the implemented functions in the form of smart contracts. The characteristics of the method were inductively derived from the formal procedures and the flow of information of the VMI concept, as well as the framework conditions of the underlying blockchain technology in accordance with Braun et al. (2005).

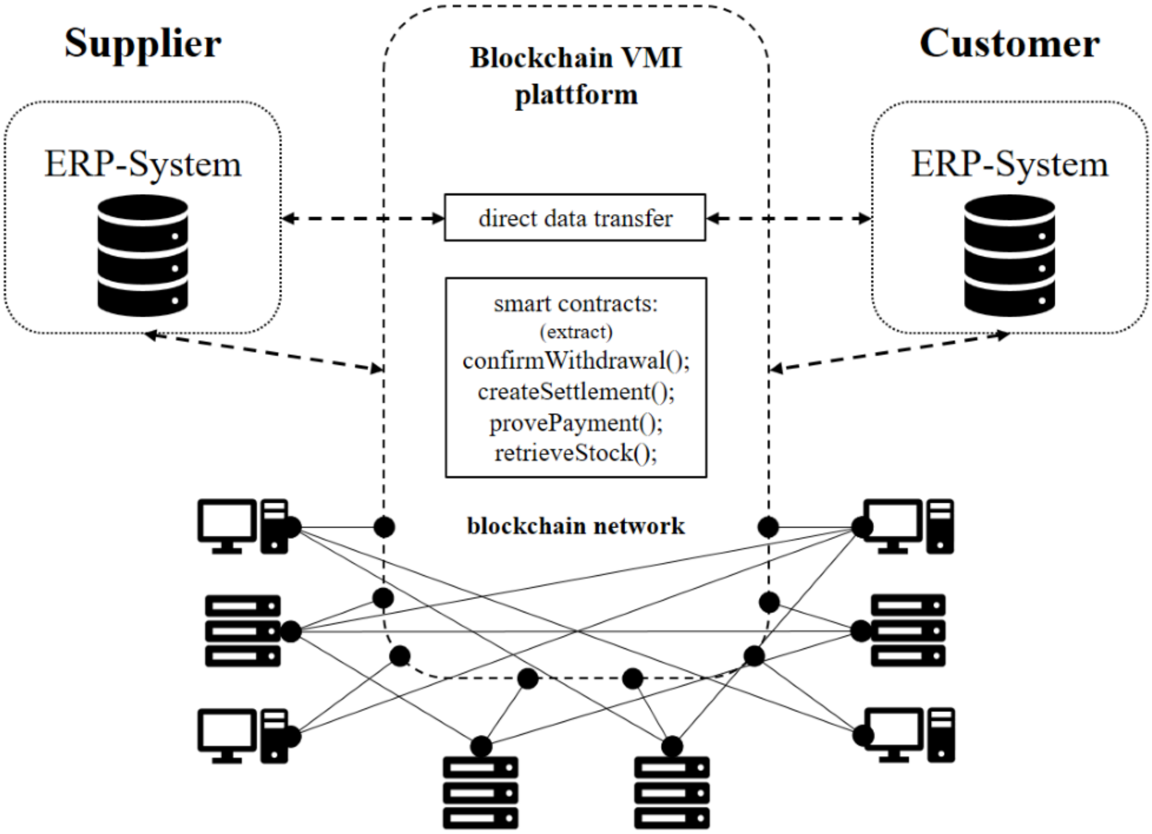

Figure 4: Visualization of the overall concept

Both the supplier and the customer usually deploy an ERP system for internal processes (Ståhl Elvander et al., 2007). An ERP system supports all operational and dispositive business processes of a company (Hossain et al., 2002; Jacob, 2008). It can carry out tasks in the form of transactions either by user input or independently, and provides the users with all necessary information to cope with their business tasks, (Kurbel, 2011). ERP systems have a high degree of integration between functions, tasks and processes across different business units, whereby the company data is stored in a central database (Abts and Mülder, 2017; Jacob, 2008). ERP systems are usually modular in structure and comprise modules for the business processes of finance and accounting, logistics, sales, service management, production, maintenance, quality management, and human resources (Abts and Mülder, 2017; Kurbel, 2011). However, many companies are not satisfied with the basic functionalities of an ERP system because, in addition to internal data, external information and analysis or decision-making is becoming increasingly important. Therefore, ERP-II systems or business suites are used to extend ERP systems so they can also support inter-company processes and supply chain management processes (Koh et al., 2011). Although inter-company communication in the form of data exchange is essential for many companies, ERP-II systems are rarely used (Gronau, 2016). Blockchain technology could therefore help increase and improve inter-company data exchange, especially in a completely reliable manner. ERP systems are connected to the blockchain via standardized interfaces in order to obtain an integrated system. Classic VMI concept processes are handled by the blockchain between supplier and customer and all information exchanged during the process are documented in the blockchain in a manipulation-safe manner according to the characteristics of this technology. The data is therefore not exclusively within the IT infrastructure of one of the participants and therefore cannot be changed or influenced by them. The integrity of the data can thus be guaranteed by the blockchain and the necessary trust relationships can be substituted. Security can be further enhanced by selecting a private blockchain with limited access rights. Depending on the industry structure, it is also possible to use a consortium blockchain with several participants. For example, automobile manufacturers and suppliers could participate in such a consortium and thus increase the number of nodes, which increases transparency and security.

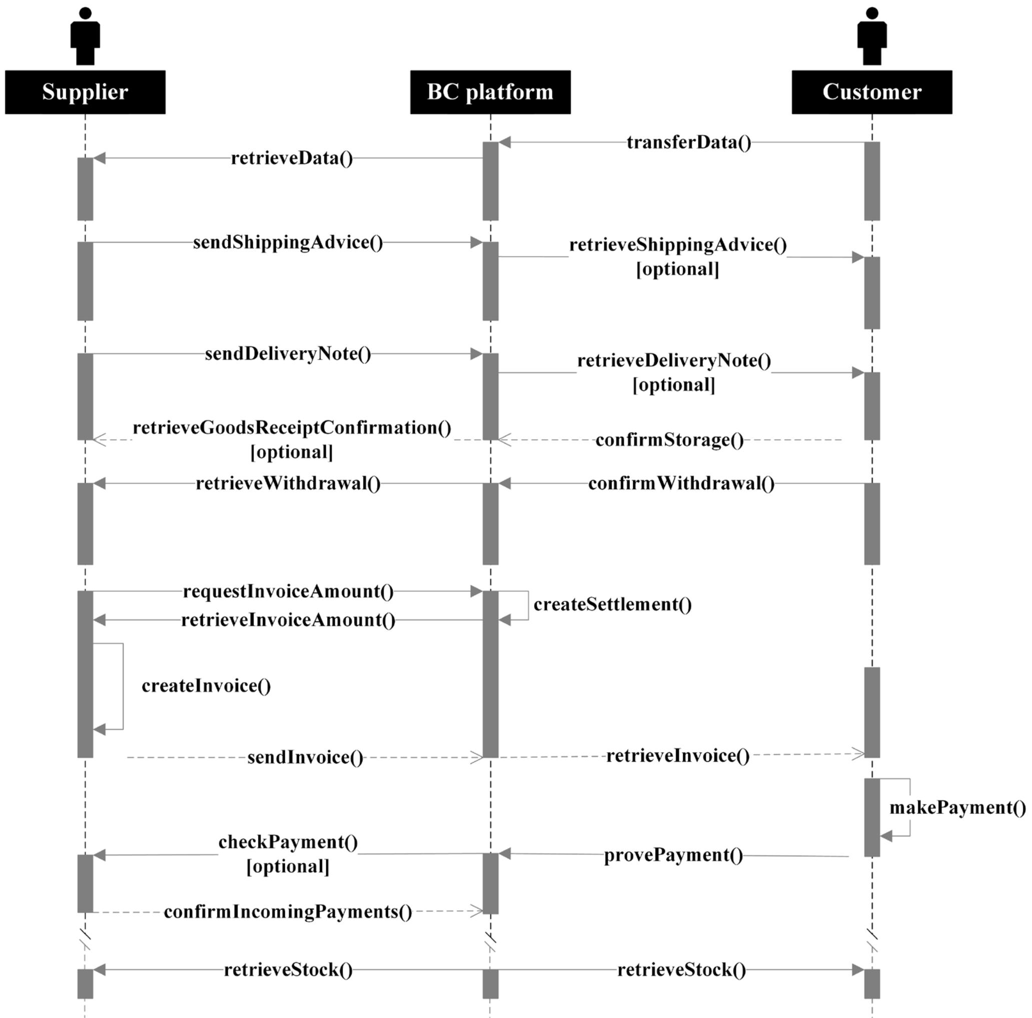

Figure 5. Available functionalities in the blockchain-based VMI system

The functionalities required for all participants in this IT artifact are illustrated in a sequence diagram (see Figure 5), which shows the interactions between the objects in sequential order. These must be implemented in the prototype in order to guarantee the basic functionalities for the partners involved, which were identified in Figure 3 and Table 1. By storing all data in the ERP system, the consumption data, demands, and other relevant data can be retrieved via the blockchain application and made available to the supplier's ERP system. For this purpose, the customer transfers his data to the blockchain platform by means of a dedicated function (*transferData*). The supplier can view and retrieve the stored data from the blockchain (*retrieveData*). Delivery planning is then executed outside the platform, e.g., in the ERP system or a decision support system (Achabal et al., 2000). The scheduling procedure is at the sole discretion of the supplier and is therefore not analyzed within the scope of this paper and can be considered in the publications of the authors Çetinkaya and Lee (2000), Dong and Xu (2002), or Yu et al. (2012). As soon as a specific delivery that includes all relevant data has been planned and scheduled, a shipping advice is sent to the customer via the blockchain platform (*sendShippingAdvice*). The customer can call up and view it from there (*retrieveShippingAdvice*). However, since delivery planning is the responsibility of the vendor, he is only interested in the availability of the goods, and the retrieval of the shipping notification is therefore offered to him or her as an option. After the goods issue, the physical delivery takes place, which is not considered further in the context of this concept. In addition, more detailed and accurate tracking would be possible based on the supplementary use of IoT technology. The accompanying delivery note can be transmitted electronically by the supplier via the blockchain platform (*sendDeliveryNote*) and is therefore available in digital form for a potential incoming goods inspection and subsequent storage. The implementation of an optional retrieval by the customer enables the customer to inspect it for control (*retrieveDeliveryNote*).

The products are then stored in a warehouse to which customer has direct access. The confirmation of storage is stored by the customer in the blockchain platform (*confirmStorage*) and can be viewed by the supplier as a goods receipt confirmation, if required (*retrieveGoodsReceiptConfirmation*). In addition, the current stock can be permanently retrieved by all parties. For this purpose, a request function (*retrieveStock*) has been implemented, which looks at all the storage and withdrawal transactions documented in the blockchain. Due to the unchangeable and transparent listing of all documents, the current inventory can be calculated traceably at any time by the implemented mechanisms. The design and legal allocation of the warehouse layout depends on the contractual agreement between the parties, usually a consignment warehouse is set up. Identification standards (e.g., RFID) and IoT applications can also be used here to improve the efficiency and transparency of the process (Choi, 2011; Szmerekovsky and Zhang, 2008) and to automatically document storage in the blockchain.

The transfer of ownership takes place when the product is taken from stock, which is normally performed by the buyer. Information about who took what at what time and what the product is being used for is kept transparently documented in the decentralized blockchain platform. The available function (*confirmWithdrawal*) confirms the withdrawal and forwards it to the supplier (*retrieveWithdrawal*). For example, if RFID or other digital identification technology is used, the process can be implemented fully automated by identifying the products at a gate with precise identification of each piece, which would considerably enhance accuracy and reduce effort.

With the withdrawal and the transfer of ownership, a settlement becomes necessary. Depending on the agreements of the participating companies and, consequently, stated specification, this can be bundled in the contract components on a monthly basis or be carried out directly after the withdrawal, hand-in-hand in an individual invoice for each product (Ståhl Elvander et al., 2007; Vigtil, 2007). The advantages and disadvantages of the respective accounting methodology are not the subject of the study, but both options are explained in the concept of the procedure and can be implemented.

For monthly or period-based settlement, a time frequency for invoicing is defined using a smart contract. The supplier requests the invoice amount from the blockchain platform (*requestInvoiceAmount*). Then the amount is aggregated (*createSettlement*) and stored on the target date by means of implemented functions through the unchangeable listing of all transactions in the billing period. The amount can then be called up by the supplier (*retrieveInvoiceAmount*). The actual invoice document is generated in the supplier's ERP system and is then transmitted to the customer via the platform and electronic exchange standards like EDIFACT INVOIC (*sendInvoice*). Once the invoice has been saved, it can be retrieved by the customer (*retrieveInvoice*). The customer's payment execution is then placed outside the blockchain again. Only the proof is stored in it (*provePayment*), which can be called up by the supplier as an option (*checkPayment*). The supplier can then confirm payments received (*confirmIncomingPayments*) and thus concludes the monthly settlement.

Another type of settlement is direct invoicing. Each individual withdrawal of goods leads to immediate invoicing and payment and therefore does not require any functionality to request the invoice amount. This reduces the capital tie-up with the supplier and greatly increases the transaction costs if an employee must manually check and instruct each individual payment. However, since the available data is verified by the blockchain, the smart contract can issue direct and automatic payments in this case. In pilot projects, personal savings of up to 90 percent were achieved for invoice verification (Tanskanen et al., 2008). As soon as blockchain has reached an increased maturity, a payment can also be made in a cryptographic currency. In this way, payments are carried out completly automatically and directly via the blockchain, thus eliminating the need for human interaction. Due to the negligible transaction costs with fully automatic processing in the blockchain application, the concept of unit-specific invoicing is beneficial and can generate cost advantages.

5.2 Development of a decentralized VMI application

The blockchain-based VMI application is based on the existing ERP systems of the partners. Up to now, the two systems have communicated with each other with their respective connected data silos, as the data relevant for the procurement process is exchanged outside the blockchain. The data, such as sales or inventory data, originates from the business processes of the ERP system and is processed there, so that it is currently transmitted via interfaces of the systems. After implementation of the prototype, the data is transferred to the blockchain platform via established standard interfaces of the systems and from there to the supplier. Each VMI-relevant process is recorded in the ERP system, either manually or via supporting technologies such as RFID, and then automatically transferred to the connected blockchain and documented there. Thus, each party has access to the same data status and has no influence on changing it unilaterally and unjustifiably.

An Ethereum blockchain is used for transactions during procurement and up to the withdrawal. The decentralized storage of the data can take advantage of the decentralized nature of a blockchain. A private test Ethereum blockchain was set up in the ERP laboratory of the University of Würzburg for the prototype. In contrast to the public blockchain, the private one is especially suitable for testing, as the application is not publicly exposed and the real cryptocurrency Ether does not have to be paid as a usage fee (Willems, 2017). In contrast, the decentralization of a private test blockchain is limited, which is sufficient to demonstrate the practicability of the method in form of a prototype.

The Ethereum blockchain especially offers the potential to be used as a protocol layer for an exemplary implementation of the method presented in the previous chapter. While the well-known Bitcoin blockchain is useful for the financial industry in its application as a pure cryptographic currency, the Ethereum blockchain is mainly used to to bypass intermediaries outside the financial sector as a part of the Blockchain 2.0 and 3.0. Ethereum enables the implementation and execution of generically programmable source code in the form of smart contracts (Buterin, 2014) in its protocol and offers a test environment in addition to the public live-network. Special programming languages such as Solidity (Java-like) or Mutan (C-like) are already available. A private or consortium blockchain is intended for later, productive use, which is operated independently by several companies.

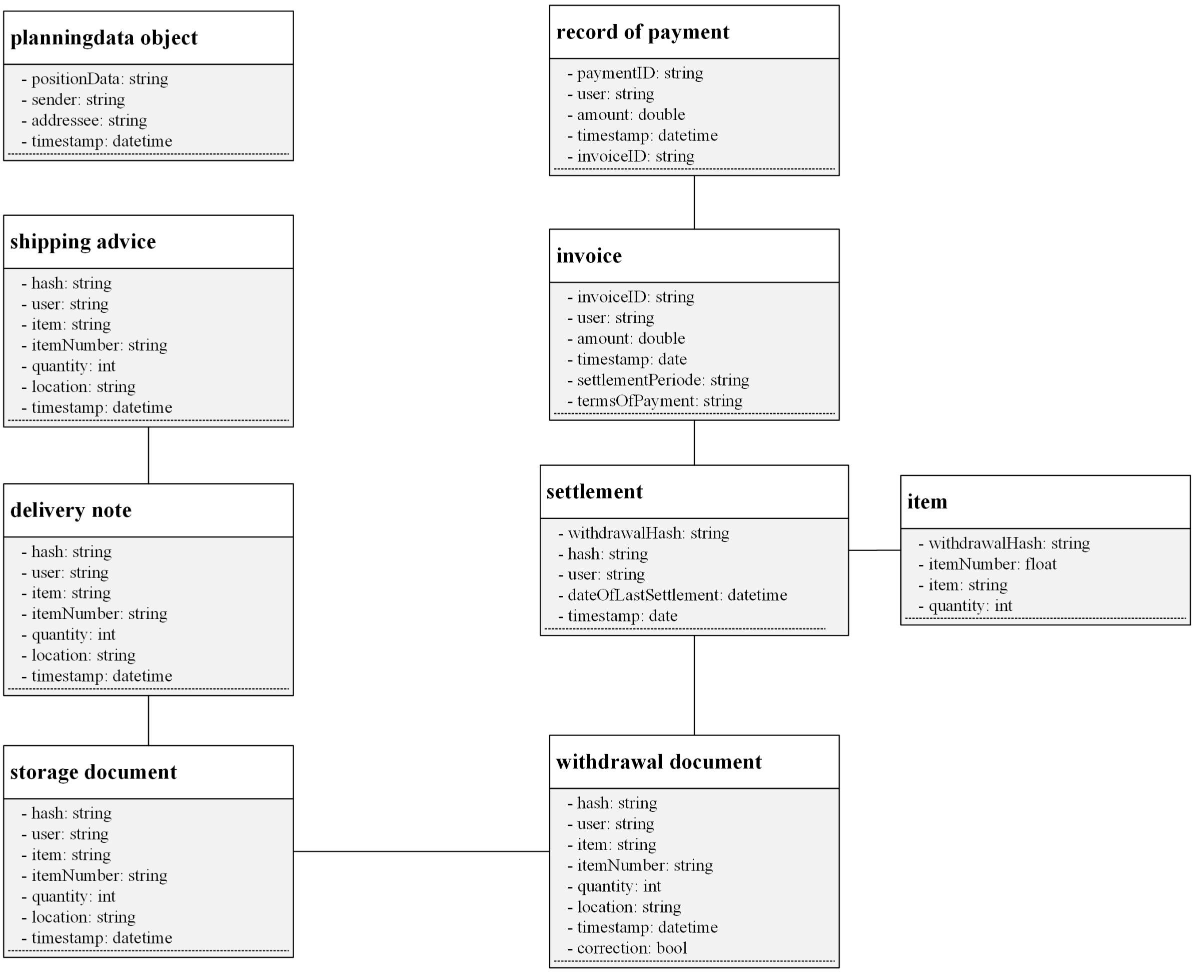

Figure 6: Illustration of the data to be transferred

Smart contracts are an important component of the functionality, containing the code for executing the VMI transactions, such as the algorithms for invoicing. Smart contracts contain all the rules of contracts in software code, ensuring that transactions are executed with absolute reliability and without human interaction. They are stored in the blockchain and executed by the Ethereum Virtual Machine. Based on these intelligent contracts, we developed a blockchain platform that simplifies contracts negotiations between several partners of the VMI. This can solve problems caused by a lack of trust or incomplete information about the other party due to the possibility of enforcing the execution of the contractual agreements triggered by the occurrence of certain events or predefined conditions (Beck et al., 2016). Smart contracts can guarantee increased complexity by allowing them to communicate with each other through messages (Beck et al., 2016). Therefore, several contracts that enable the required functionalities were drawn up for the prototype. For example, contracts exist for the withdrawal or the settlement. The most common programming language, Solidity, was used for the development of smart contracts.

The ERP data can be extracted within a REST interface (we used the Open Data Protocol OData) in JSON data format from ERP systems and then transferred to the blockchain via the JSON RPC API from Ethereum an O.js. The transferred data had to be identified in order to develop the prototype. For this purpose, the relevant documents within the systems, such as the withdrawal document, were examined and the important data fields were selected. The requirements are determined by the VMI process in Table 1 and Figure 3. Information about delivery and withdrawals are critical data, which need a mutual trust without the blockchain and therefore have to be transferred into the platform. The results are illustrated in an UML class diagram presented in Figure 6.

Access to the public blockchain platform still requires a specific browser like AlethZero or Mist (Beck et al., 2016), but standardized interfaces for machine-to-machine communication are available. This allows easy and flawless connectivity to any IT and information system with minimal effort regarding adaption of the blockchain-based VMI platform. In order to test the application, we used a private test blockchain based on Ethereum (TestRPC), which already includes different wallets. We used Remix as an IDE and the programming language Solidity to create the source code of our smart contracts in the next step. All information and functions are available via a frontend user interface which is presented in Figure 7. A manual start of the processes was necessary for prototypical implementation and evaluation, but this can be automated with little effort.

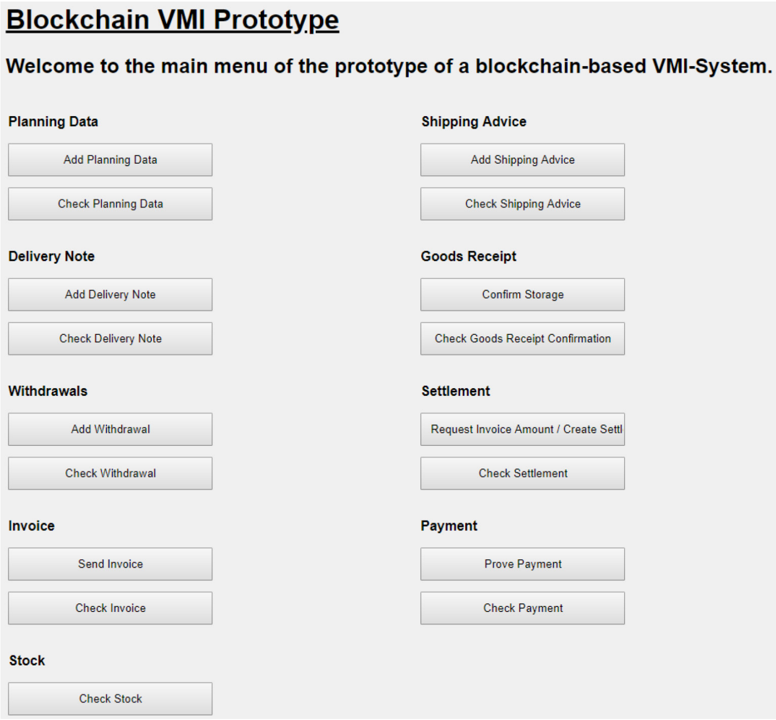

Figure 7: Frontend of the Blockchain VMI Prototype

In summary, a prototype was implemented and deployed on servers at the University of Würzburg in order to demonstrate the feasibility of the method and to evaluate its usefulness in accordance with steps 4 and 5 of the DSR approach within a basic scenario. The implementation of a prototype and simulation of its operation is a suitable technique to evaluate a method (Prat et al., 2015). Several EPR systems were available for the evaluation at our ERP research laboratory at the University of Würzburg. We decided to use the common system Microsoft Dynamics NAV and the cloud-based ERP system weclapp because of their high prevalence and relevance, especially for small and mid-sized enterprises, as well as their well-designed interfaces. The basic functionalities were then tested on the basis of some sample data and processes that could occur in an everyday use scenario. Since there were problems using the weclapp API due to missing functionalities, two clients were used on a Microsoft NAV 2018 system to represent the supplier and the customer. The decentralized storage of all data in the blockchain as a confidence-building measure for the VMI concept is practicable and has proven useful in means of traceability and simplicity of implementation compared to alternative methods for connecting two ERP systems. In the future, we plan to implement the concept with at least two business partners in order to advance the maturity of the prototype and show its superiority to previous VMI implementations within a scenario-based evaluation with real time data. Besides, additional enhancements are expected to further automate the process in the future. Great further potential arises from the combined use of other technologies for tracking goods, such as RFID and IoT. Automation using such technologies leads to the avoidance of human intervention, which further reduces the potential for error. Furthermore, cryptocurrencies will offer an interesting enhancement option in the form of a fully automatic payment system. Machine-to-machine communication enables direct settlement and payment in the form of virtual currencies at low transaction costs. At the present time, however, cryptocurrencies are proving too volatile to be used as a means of payment.

6 Summary and future research

In this paper, the requirements and information flows of a VMI system were pointed out and mapped towards the characteristics of the blockchain technology aiming to prove the feasibility of this procedure via this technology. The processes were explained and the representation of these in the blockchain was clarified in chapter 5. The combination of these techniques forms a method for complete blockchain-based VMI process, which is presented in this contribution and thus compile the final step of the DSR approach.

In theory, the concept of VMI has diverse advantages compared to other forms of replenishment, but is still not widely used in practice. As stated in the introduction, this is caused by two major weaknesses. First, the need for noticeable initial investment in the setup of such a relationship, especially the adaption of the business applications, like ERP systems, with their data silos and the implementation of appropriate interfaces to create the ability to send and receive the necessary business information, as well as the conclusion of specified contracts. Second, the need for mutual trust on both sides, for example, that the delivered data regarding product consumption, sales, and settlement are useful in terms of correctness, validity, and accuracy, that the business partners are capable of delivering those data frequently and dependably, and that the data are stored confidently, immutably and securely. The proposed method of a blockchain platform enabling the establishment of a VMI relationship offers the potential to deal with both weaknesses. On the one hand, investments are cut because all relevant transactions and information flows are realized via the blockchain connecting the ERP systems in place via standardized interfaces. On the other hand, the blockchain technology is useful to substitute the need for trust on the basis of the inherent characteristics of this technology. The transparent, tamper-proof data storage in the distributed ledger demonstrates the superiority of our proof of concept compared to traditional VMI systems. All data, and thus all incoming receipts, are stored permanently and unchangeably in the blockchain. In conclusion, the concept offers added value in comparison to the classic VMI. For this reason, the target of a proof-of-concept evaluating the practicability and usefulness of a blockchain-based VMI process is considered fulfilled, but must be further evaluated in practice. The concept presented here can thus contribute to the propagation of VMI as an opportunity to gain advantages in replenishment processes in comparison to existing processes. Thus, research question 1 - how a blockchain-based VMI relationship is qualified to deal with the weaknesses of traditional implementations of VMI - can be regarded as answered. Furthermore, a method of description was developed using the DSR procedure in order to answer the second research question, how blockchain applications can be implemented into enterprise operations. The method consists of three central components. The first component is the technological basis of this concept, consisting of a third generation blockchain as a reliable data storage location and flexible data exchange platform based on the Ethereum blockchain. This is connected to the ERP systems of participating companies via standardized REST interfaces. The second component is a class diagram that ensures all the information required to use a VMI process is included in the method. The business documents usually used and exchanged in traditional VMI were reduced to their essential information content. The third component is a functional diagram that covers the transactional information flows of VMI partners using smart contracts. In the same way, other business procedures and logistical concepts can also be implemented by means of blockchain technology, so that the second research question can also be regarded as answered.

Limitations of the work result from the fact that the method has only been evaluated under laboratory conditions with a prototype. In order to measure the gain of utility of this concept compared to existing realizations of VMI relationships, and therefore, to justify this method, a broader evaluation with business partners is pending but planned in the future. Also, an extension to other application scenarios is conceivable and left out as a subject of further research.

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