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Toward a Decentralized Marketplace for Self-Maintaining Machines

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***Abstract*—Industrial procurement processes are inefficient, expensive, and error-prone as they require the agreement of numerous participants, audit-proof documentation, and are characterized by a high number of manual tasks. Blockchain technology has the potential to counter these challenges by combining peer-to-peer networks, cryptography, and consensus algorithms. A blockchain is a decentralized database that stores transactions and data transparently, chronologically, and tamper-proof in a distributed network. In this paper, we present a blockchain-based industrial marketplace, where machines have an identity and account for selecting, ordering, and paying materials in an automated manner using smart contracts. This allows manufacturers with a low real-net-output-ratio, such as car manufacturers that depend on numerous suppliers, to optimize their purchasing processes. Using our case study, we demonstrate prototypical implementation of the decentralized marketplace and its applications in the area of industrial maintenance. Furthermore, we conducted a semi-structured interview with procurement and information technology experts from the automotive industry. The results indicate that our prototype offers a promising approach streamlining procurement processes within the next two to five years.**

***Index Terms*—Blockchain Technology, Smart Contract, Machine-to-Machine Economy, Smart Maintenance, Smart Procurement, Industry 4.0**

I. Introduction

Procurement describes the process of acquiring materials or services from external partners. Procurement processes are characterized by a high number of manual activities, the coordination of numerous external sources, and high costs (e.g., for escrow services). Due to the growing complexity and individualization of products, manufacturers are facing an increasing number of parts and part variants, which in turn lead to a growing number procurement tasks. As a result, current industrial procurement processes are inefficient, expensive, and error-prone.

In the following, we will concentrate on procurement processes in the automotive sector, where around two thirds of the value added is generated by external partners. Therefore, optimizing existing processes and integrating new processes that increase efficiency and transparency is key to remaining competitive. The goal is to increase automation rates, accelerate international financial transactions, and build a trusted infrastructure to ensure the integrity of procurement processes and the liquidity of companies. Blockchain technology presents promising opportunities for countering these challenges and add new value to industrial procurement processes (see e.g., [1]–[3]). Blockchain is a decentralized database that stores transactions transparently, chronologically, and tamper-proof in a distributed network [4]. It provides the foundation for securely exchanging tangible (e.g., materials) and intangible assets (e.g., digital currencies). Integrating blockchain technology into industrial procurement processes represents the first step toward a machine-to-machine economy, which describes the vision whereby machines become active participants in business processes.

In this paper, we present a decentralized industrial marketplace for materials using an example from industrial maintenance. The blockchain-based marketplace enables machines to have a secure and trustworthy digital identities and their own accounts. Hence, machines can select, order, and pay for materials (e.g., consumables and spare parts) in an autonomous manner using smart contracts. Each step of the procurement process is reliably recorded on the blockchain, creating a tamper-proof audit-trail. We show that blockchain has the potential to streamline and accelerate procurement processes and reduce costs by eliminating the roles of intermediaries (e.g., banks). We demonstrate the feasibility and potential of blockchain in a case study that involves 10 companies, 50 machines, 10 quotations, and over 1000 transactions.

This paper is structured as follows. In Section II, we provide an overview on foundations and a structured review on the investigated literature. Section III presents the vision and conceptual structure of the decentralized industrial marketplace, and describes the vision, requirements, and the proposed system design of the marketplace. In the case study in Section IV, we discuss the prototypical implementation of the Smart Contracts using the Hyperledger Fabric Blockchain framework. We validate the prototypical implementation in Section V by means of a semi-structured interview with experts from the industry. Section VI summarizes the paper and its contributions.

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II. Background and Related Work

This section describes relevant foundations on which our decentralized marketplace is based on and reviews the related work.

A. Blockchain Technology

Blockchain technology is a type of distributed ledger technology (DLT) that refers to a decentralized database, which is distributed across multiple nodes and locations. Blockchain was first developed by Satoshi Nakamoto in 2008 as the underlying technology for the cryptocurrency Bitcoin [4]. A blockchain network records and shares data in a secure trusted, and tamper-proof manner using cryptography and consensus algorithms without the need for a trusted third-party [5]. A blockchain is a list of blocks that consists of a timestamp, a nonce, a hash value, and transactions as payload [4]. Each block is linked to its previous block through a cryptographic hash. Consensus algorithms ensure that the decentralized and distributed databases are kept consistent and thus, provide a single source of truth [6]. Several approaches exist for reaching consensus in blockchain networks. In public blockchains such as Bitcoin and Ethereum, anyone can access the network. Data and transactions are visible to all participants and everyone can join the consensus process [7]. Consensus in public blockchains is mainly realized through Proof-of-Work (PoW) and Proof-of-Stake (PoS). In private blockchains such as Corda and Hyperledger, only pre-selected nodes can access the network and participate in the consensus process [7]. Therefore, they can use more efficient consensus algorithms such as Practical Byzantine Fault Tolerance (PBFT) algorithms, which focus on speed and scalability.

B. Smart Contract

Nick Szabo [8] first described the idea of smart contracts as a digital protocol that automatically carries out the terms of an agreement. Ethereum was the first general purpose blockchain framework that provided the ability to integrate smart contracts [9]. Smart contracts provide a programmed algorithm that can be used, e.g., for executing contracts or automating business processes [10]. This makes it possible for agreements and transactions to be carried out among parties or machines in a traceable, transparent, and irreversible manner without the need for a trusted third party [11]. Benefits of smart contracts include reducing errors, time and costs for verifying and executing processes [10], [12], [13].

C. Procurement

Following [14], procurement describes the "management of the external resources of an enterprise." The overall goal of procurement is to secure the availability of all materials and services that are needed for realizing and steering the primary and supporting activities of a company [14]. Purchasing desribes a subset of procurement and refers mainly to buying materials or services. Procurement tasks can be divided into strategic and operational tasks [14], [15]. The focus of operational procurement is to meet daily purchasing needs, such as ordering materials and services, monitoring orders, and evaluating suppliers [14]. Strategic tasks deals with long-term sourcing objectives of companies, such as supplier portfolio management and improving purchasing processes [14], [16].

D. Maintenance

Maintenance is defined as any task performed that keeps technical equipment in or returned to proper working condition [17]. There are two major maintenance tactics, namely corrective and preventive maintenance [17], [18]. Corrective maintenance is performed after detecting the failure (e.g., due to an unexpected breakdown of a machine) [17], [18]. Preventive maintenance includes time-based and condition-based maintenance activities for detecting and correcting incipient failures of machines before failures occur [17], [18]. Condition-based maintenance monitors the condition of machines using sensors to estimate when maintenance services need to be performed [17], [18].

E. Related Work

For the design of our literature review, we rely on methods presented by Bandara et al. [19], vom Brocke et al. [20], and Webster and Watson [21]. Based on this, we derive four steps: Subsequent to a literature search (1), relevant articles are identified (2) and further analyzed (3). Afterward, the results of the analysis are structured (4). With the aim of analyzing a wide range of research literature, we query the databases listed in Table 1. We use search terms for blockchain technologies and related concepts (i.e., distributed ledger technologies, smart contracts) and link them via an `AND` operator to terms that ensure search results within marketplaces and relevant industrial application domains such as procurement and maintenance.

TABLE I
Parameters of Keyword Search

Databases	arXiv, IEEE Xplore, Research Gate
Search Fields	Title, Abstract, Keywords
Source Types	Journales, Conferences
Search Term	("Distributed Ledger" OR "Blockchain" OR "Smart Contract") AND ("Procurement" OR "Purchasing" OR "Maintenance" OR "Marketplace")

The search strategy renders a total of 181 results. Relevant papers were selected by analyzing titles, abstracts and full text. The literature analysis results in 19 papers (doubles removed). All relevant papers were published after the year 2016. When looking at the year distribution of the selected papers, 1 paper (5%) was published in 2016, 3 papers (16%) in 2017, 14 papers (74%) in 2018 and 1 paper (5%) was published in 2019. Regarding the geographic distribution of the selected papers, the top countries of authors are Germany (21%) and the United States of America (16%). Furthermore, we clustered the publications by the type of marketplace and procurement tasks (Table I). Thus, assigning one paper to multiple criteria is possible.

TABLE II
OVERVIEW OF THE INVESTIGATED LITERATURE

Application Areas	Papers
A. Marketplaces	
Data Marketplace	[1], [22]–[31]
Digital Asset Marketplace	[23], [27], [29], [32], [33]
Physical Asset Marketplace	[1], [3], [28], [29], [34]
B. Procurement Use Cases	
Payment Infrastructure	[22]–[27], [29]–[33], [35]–[37]
Contract Creation	[1]–[3], [35]
Order Management	[1]–[3], [34], [35]
Regulatory Transparency	[2], [3], [26], [36]
Demand Planning	[1], [3], [28]
Supplier Evaluation	[1], [2], [29]
Tracking and Tracing	[2], [3], [36]
Price Negotiation	[2], [36]
Supplier Selection	[2], [36]

Blockchain technology has been considered as a possible solution for marketplaces due to ownership neutrality [22], [29], data integrity [29], [32], data privacy [22], [24], [29], and security [22], [29].

In the field of marketplaces, 44% of articles were published on *Data Markets* (e.g., trading of consumer data), 28% percent deal with *Digital Asset Marketplaces* (e.g., purchasing apps for edge devices) or *Physical Assets Marketplaces* (e.g., purchasing consumables in industrial manufacturing), respectively.

The following procurement use cases are mentioned in order of frequency of response (cf. Table I). The majority of publications deals with *Payment Infrastructure*, such as procure-to-pay processes using blockchain technology. Other use cases include automated *Order Management* by machines [1], [3], *Supplier Evaluation* [1], [2], *Tracking and Tracing* of materials in complex supply chain networks [2], [3], [26], [36], and *Price Negotiations* such as e-auctions [2].

In the following, we refer to publications that are closely related to the vision of our decentralized industrial marketplace. For example, Bahga et al. [1] introduce a blockchain-based platform for industrial internet of things in manufacturing enabling machines to execute micropayments for consumables. Nicoletti et al. [2] describe an auction system based on smart contracts to store negotiated contracts and automate settlement improving data integrity, security, and transparency. Seitz et al. [32] introduce a decentralized marketplace for industrial edge applications that relies on blockchain to create transparency for all stakeholders involved and to enable the traceability of app installations on edge devices. Teuteberg et al. [3] propose a blockchain-based order process for increased auditability and automation enabled using smart contracts. However, research at the interface of blockchain technology and industrial procurement processes in terms of theoretical concepts and empirical evaluation (e.g., implementation of prototypes) is yet scarce. In addition, there is no holistic approach that combines the various industrial procurement tasks on a single blockchain-based marketplace.

III. MARKETPLACE

In this section, we describe the vision, functional and non-functional requirements, and the architecture of the decentralized industrial marketplace.

A. Vision

In our vision machines become self-determined market participants in industrial environments. Machines are able to interact with other machines or humans over an industrial decentralized marketplace. Suppliers can initiate quotations into the decentralized marketplace. Buyers of companies serve as quality gate and have to approve initiated quotations as materials have to meet companies standards to make them available to their machines. Smart contracts enable machines to perform various actions such as selecting quotations, ordering materials from other machines, and booking of maintenance services in an automatic and audit-proof manner. Machines are able to confirm the arrival of material, pay for them, and rate the supplier performance based on defined criteria. By running on a peer-to-peer network, participants have control over the marketplace and machines can use digital currencies and escrow services, which only release money once the materials have been delivered. Furthermore, service engineers can document performed services and installation of spare parts in a digital service book increasing the resale value. The digital service book can be shared with authorized third parties.

B. Requirements and Approach

There are different procurement and awarding methods, including the marketplace principle and request for quotation (RfQ) process, which focuses on standard and specific materials and services, respectively. In the marketplace principle, machines are able to select materials based on an algorithm based on quotations approved by buyers of the associated company. Buyers and suppliers are responsible for ensuring that quotations are available in the marketplace and are selectable for machines. In the RfQ process, machines actively ask for specific materials. Requested suppliers participate in a bidding process. In this paper, we consider the marketplace principle as it represents the first step towards an automatic selection process of machines using current technological capabilities.

The following functional and non-functional requirements must be met to successfully implement an industrial marketplace for self-maintaining machines:

(1) Quotation Management: Suppliers must be able to initiate quotations into the marketplace. Buyers must be able to approve quotations to make them available to their machines.
(2) Order Management: Machines must be able to select approved quotations in the marketplace to create an order for materials. Furthermore, machines must be able to confirm the arrival of materials.
(3) Supplier Evaluation: Machines must be able to evaluate the performance of suppliers.

(4) Financial Transactions: Machines must be able to execute payments to other machines or suppliers.
(5) Digital Maintenance Book: Service engineers must be able to record their performed maintenance services and the installation of materials.
(6) Independence: The marketplace should be a decentralized system in which there is no regulating authority.
(7) Traceability: All activities and events must be documented for regulatory reasons in an audit-proof manner. The records must be traceable for the involved participants.
(8) Access Control: The marketplace should only be accessible to registered participants and machines.
(9) Privacy: The marketplace must be able to make private transactions.
(10) Data integrity: The marketplace must assure the accuracy and consistency of data.
(11) Availability: The marketplace must be available at any time.
(12) Scalability of Transactions: The marketplace must be able to process a large number of transactions.
(13) Scalability of Participants: The marketplace must be able to include a large number of participants.

C. Analysis

We created the analysis object model (see Figure 1) to better describe the structure of the problem domain and the relationships among the objects.

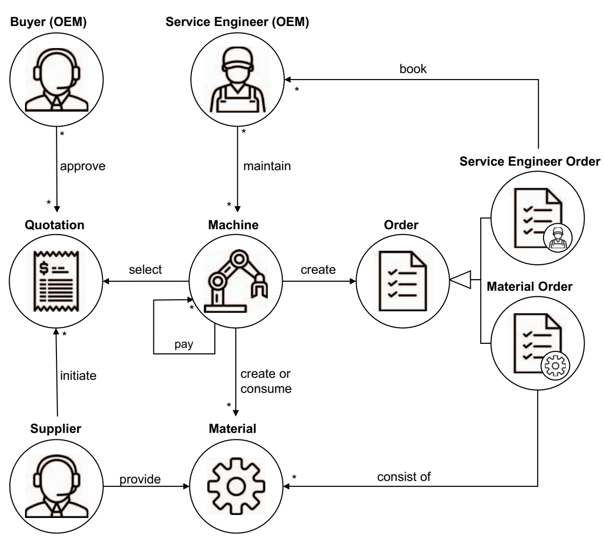

Fig. 1. **Analysis Object Model:** The model supports to better understand the problem domain and to develop the solution approach of our concept.

There are four participants that interact with the marketplace, namely *Supplier*, *Buyer*, *Machine*, and *Service Engineer*. *Suppliers* can initiate *Quotations* into the marketplace and provide *Materials*. *Buyers* can approve *Quotations* that meet corporate standards, to create a purchasing framework for their *Machines*. *Machines* can select approved *Quotations* based on a selection algorithm that takes criteria such as price and supplier rating into account, and can place *Orders* for required *Materials*. In case maintenance services (e.g., the installation of a spare part) are required, *Machines* can also book a *Service Engineer* for the planned arrival time for *Materials*. *Machines* can confirm the arrival of materials, pay for them, and evaluate the *Supplier* based on its performance. Supplier ratings can be used by all participants in the marketplace. After the *Service Engineer* has serviced the *Machine*, the performed services and installed *Materials* are recorded on a digital maintenance book.

The analysis of the problem domain is kept as generic as possible to represent a multitude of scenarios. The *Order* taxonomy allows us to extend and adapt our system.

D. Architecture

Figure 2 shows the proposed architecture for the decentralized industrial marketplace, which focuses on the main components and technologies of the solution approach. It comprises the following four layers: *Physical*, *Application*, *Middleware*, and *Distributed Ledger*.

(1) Physical Layer: The *Physical Layer* contains *Materials*, *Quotations*, *Orders*, and *Machines*.

(2) Application Layer: The *Maintenance Mobile App*, *Marketplace Web App*, and *Machine App* are used to create, monitor, and share digital representations of assets of the *Physical Layer*. Before users and *Machines* can interact with the *Permissioned Blockchain*, they need an invitation that must be validated by one or more participants, who are allowed to manage the marketplace permissions via the *Marketplace Web App*. To interact with the marketplace service engineers use the *Maintenance Mobile App* on the shopfloor, buyers and sellers use the *Marketplace Web App*, and *Machines* use the *Machine App*.

(3) Middleware Layer: The *Communication Gateway* works as an adaptor for the *Application Layer*, the *Permissioned Blockchain*, and the *Off-Chain DB* and is responsible for the communication. The *Maintenance Mobile* and *Marketplace Web App* can initiate, read, and write requests and transactions to the *Communication Gateway* on the *Middleware Layer*, which transmits it to a company *Node* in the *Distributed Ledger Layer*. In contrast, each *Machine* within its *Machine App* operates its own *Node*, which allows it to have a blockchain identity and account. The *Communication Gateway* can fetch metadata such as the participant's address from the *Off-Chain DB*, which represents the database of other existing systems, such as enterprise resource planning systems.

(4) Distributed Ledger Layer: The *Distributed Ledger* provides data storage and ensures the execution of smart contracts in a decentralized and trusted manner. The marketplace uses a *Permissioned Blockchain*, which provides a selective level of privacy as well as low transaction times and costs. Therefore, it is very feasible to introduce further transactions and participants. Each activity such as the payment of material is recorded and is thus traceable on the *Permissioned Blockchain*.

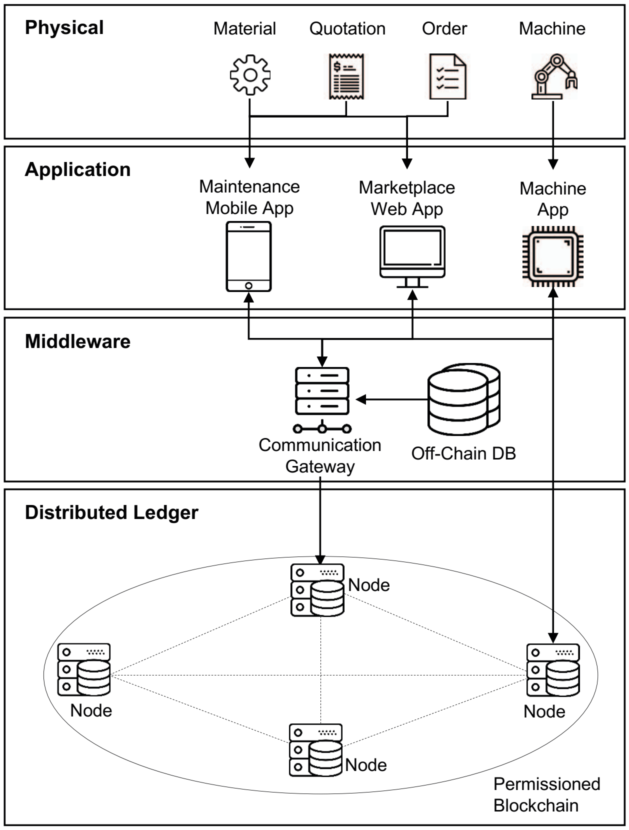

Fig. 2. **Top Level Design:** The marketplace architecture consists of four layers including the Physical, Application, Middleware, and Distributed Ledger. The Maintenance Mobile App, Marketplace Web App, and Machine App act as interfaces and allow the interaction among the Physical Layer, the Off-Chain DB, and the Permissioned Blockchain.

IV. Case Study

In this section, we discuss the application of the proposed industrial marketplace concept and the status of our prototype. We present a discussion of payment implementation options and the required smart contracts.

A. Objectives

The prototype is used to verify the technical feasibility of the industrial marketplace concept and to examine feedback by our industry partner. In the case study, we focus on the implementation of the smart contracts for the decentralized marketplace using Hyperledger Fabric. Therefore, not all parts of the proposed architecture (e.g., user interfaces) were implemented.

B. Payment Implementation Options

There are different options that provide digital currencies in blockchain-based systems:

Digital Currencies: Existing digital currencies / cryptocurrencies such as Bitcoin or Ether can be used that provide easy access and divisibility into fractions enabling micro payments. However, due to the high volatility, low acceptance, and lack of regulation the use of existing digital currencies is not recommended.

Fiat Tokens: Central banks such as the European Central Bank can issue fiat tokens based on blockchain technology offering low volatility. However, users must trust the central bank as a regulating authority. The maturity of this scenario is expected to be reached in more than ten years.

Asset-backed Tokens: A consortium can create a stable digital currency, which is for example pegged to an existing fiat currency that can be validated either on-chain or off-chain (i.e., balances are stored in an off-chain database) In case of off-chain validation, users must trust the gateway as a single point of failure and the operator as a regulating authority. In case of on-chain validation, users must trust the consortium, but there is no single point of failure. This scenario can be implemented immediately, providing lower volatility than pure digital currencies, auditability, and low transaction times and fees. Since one of the requirements of the system is independence, there is no regulatory authority, we choose the on-chain solution for our prototype.

C. Smart Contract Implementation

We implemented a proof-of-concept prototype consisting of nine smart contracts to demonstrate the technical feasibility of the proposed industrial marketplace concept (see Figure 3). The implemented smart contracts can be divided into the three areas: *Marketplace*, *Quotation*, and *Order Management*.

Marketplace Management: Users with access to the marketplace management can *Create and Delete Companies* and associated *Users*. Each user of a company can be assigned specific roles (e.g., buyer, supplier, service engineer, or administrator) with different attributes and permissions. For example, the supplier role has additional attributes (e.g., *OnTimeRate*), which are needed to determine the supplier evaluation. Service engineers can *Register Machines* on the decentralized marketplace for their company. Each machine must be equipped with a unique identifier (e.g., RFID or QR Code), which is used as a machine's identity in the marketplace. In addition, each machine has an array of slots for managing materials (e.g., consumables and tools) and maintains a digital maintenance book on the blockchain network.

Quotation Management: A supplier can *Create a Quotation* for materials. Quotations published in the marketplace are binding and verifiable. The price of a quotation is valid for a certain period of time and can be adjusted. None of the other parameters in the quotation can be changed. The quotation status is initially set to `NOT APPROVED` since it was not checked by buyers from any of the registered companies. Buyers from registered companies are notified about new quotations on the marketplace. If the quotation fulfills the requirements and quality standards of a company, the buyer can *Approve a Quotation*, changing its status to `APPROVED`. Subsequently, the quotation is selectable for all of the company's machines.

Order Management: Machines continuously monitor their state (e.g., stock level, tool condition) and decide if they need

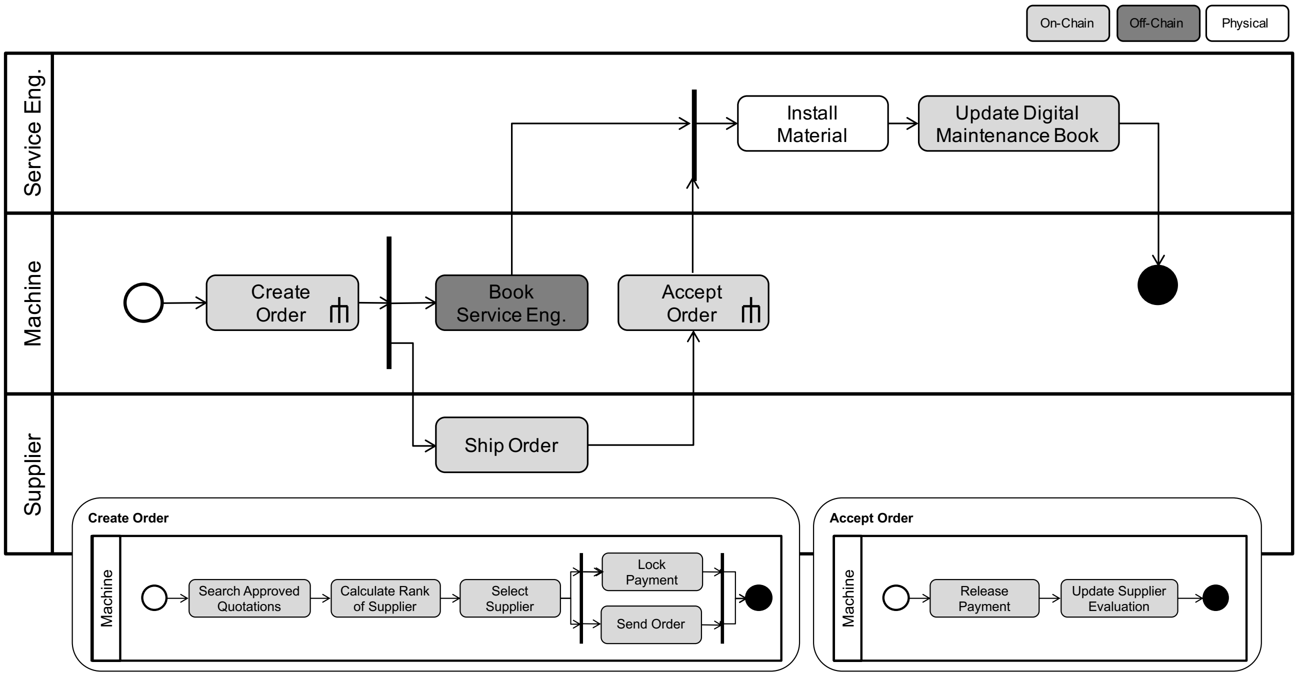

Fig. 3. **Activity Diagram for Order Management:** Visualization of the main process and two sub-processes performed by the machine, supplier, and service engineer. In addition, the on-chain and off-chain data management is shown.

to *Create an Order* for materials or maintenance services. We therefore distinguish between corrective triggers (e.g., low material stock) and preventive triggers (e.g., time-based maintenance services). In general, a machine *Searches the marketplace for Approved Quotations* for the required material number. Based on the price (p) of the required material (i) and the evaluation (e in percent) of a supplier (j), the machine *Calculates the Rank of the Suppliers*.

In the prototype, we use the following quotation for the rank (R) of a supplier (j):

$$R(j) = e(j) * (1 / p(i))$$

Machines *Select the Supplier* with the highest ranking. Thereupon, the smart contract locks the payment from the account for the machine, orders the required material number via the industrial marketplace, and sets the status of the order to *OPEN* This procedure minimizes the counterparty risk. In the event that a maintenance service is also required (e.g., for the installation of a tool), machines can book a service technician off-chain, since this is an internal company process. This sets the status of the service order to `BOOKED`. If the requested and actual delivery times for the materials match, machines *(Accept the Order* by scanning the order identifier (e.g., RFID or QR Code) on the received package. The order status is set to `DELIVERED` and the stock level of the receiving machine is updated. Next, the smart contract *Releases the Payment* to the account of the supplying machine and the order status is set to `CLOSED`. In addition, the machine *Updates the Supplier Evaluation* on the marketplace by comparing the requested and actual delivery times for the order. When carrying out maintenance services, service engineers scan the machine's identifier and *Install the Material*. The service engineer *Updates the Digital Maintenance Book* on the blockchain by recording the performed maintenance service including information about the installed materials (e.g., identifiers and timestamp). Next, the maintenance service order is closed and the status is set to `CLOSED`.

V. Evaluation

In this section, we evaluate the proposed decentralized industrial marketplace design in terms of requirements fulfillment and a semi-structured interview with thirteen procurement and information technology experts from the automotive industry.

A. Requirement Fulfillment

We examined the implemented prototype against the functional and non-functional requirements identified in Section III-B. Requirements for *(1) Quotation Management*, *(2) Order Management*, *(3) Financial Transactions*, *(4) Supplier Evaluation* and *(5) Digital Maintenance Book* were fulfilled by introducing smart contracts that express the business logic for procurement tasks as code. Furthermore, *(8) Access Control* and *(9) Privacy* requirements were archived by using a permissioned blockchain, which provides a permission system. The use of blockchain technology addressed the requirements for *(6) Independence*, *(7) Traceability*, *(10) Data Integrity* and

(11) Availability. Requirements for *(12) Scalability of Transaction* and (*13) Scalability of Participants* were not evaluated with the current prototype and thus, must be investigated in future research.

B. Semi-Structured Interview

We conducted a semi-structured interview with thirteen experts from our industrial partner in order to identify opportunities and challenges of using blockchain technology in procurement and to evaluate the implemented prototype. Of the thirteen experts interviewed, eight experts were from the procurement and seven experts from the IT department, working in the field of blockchain technology. We follow [14]–[16], [38] to identify relevant operational and strategic procurement tasks, which serve as the basis for the designing of the questions for the semi-structured interview. Figure 4 shows the influence of blockchain technology on operative and strategic procurement tasks.

First, we explained the technical basics of blockchain technology as well as the operational and strategic procurement tasks to the experts. Next, the prototype of the decentralized industrial marketplace was presented, after which the experts rated the influence of blockchain technology on the identified procurement tasks on a scale from "0" (no influence) to "5" (very high). Furthermore, they estimated the time required for introducing blockchain technology into operational and strategic procurement tasks on the basis of the categories of "less than 2 years", "2 to 5 years", "5 to 10 years", and "more than 10 years". Finally, we discussed the challenges the experts see for adopting blockchain in procurement and the further potential they see for combining blockchain and AI.

The potential of blockchain technology for operational tasks (mean values: 3.22) was rated higher than for strategic tasks (mean value: 2.88) by the respondents. For **operative procurement tasks**, the respondents see the highest potential in *Ordering and Payment* (77%) and the *Monitoring of Orders* (69%). All other operative procurement tasks indicate a medium potential. For **strategic procurement tasks**, approximately half of the respondents (54%) see the highest potential in *Negotiation Management*, *Process Optimization* and *Purchasing Controlling*, whereas *Strategic Demand Planning* and *New Technology Implementation* using blockchain technology was ranked low. Other strategic tasks are expected to be influenced moderately in the future. The time for adopting blockchain in procurement processes is estimated at two to five years for operational tasks and five to ten years for strategic tasks.

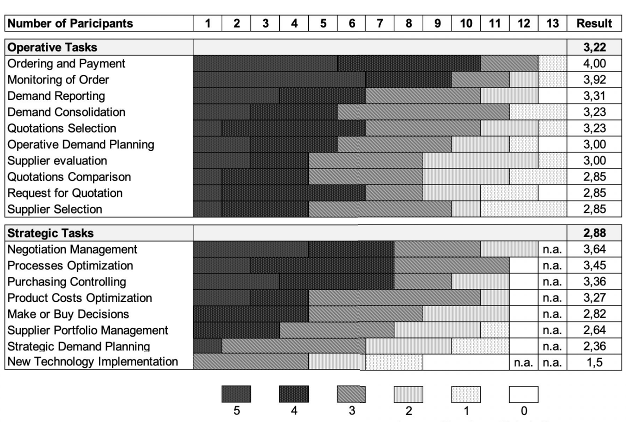

Fig. 4. **Results of the semi-structured interview:** Influence of blockchain technology on operative and strategic procurement tasks.

Overall, the results of the respondents show that IT experts see greater potential for our prototype compared to procurement experts. The highest potential was seen for *Negotiation Management* from an IT standpoint and *Order Management* from a business standpoint, respectively. The results from our procurement experts show a higher standard deviation, which indicates a higher uncertainty.

The main barriers for blockchain adoption are regulatory uncertainty and technical standardization (77%), such as interoperability and data exchange among separate blockchain networks. These are followed by technological readiness and scalability of blockchain-based systems (69%), employee resistance (62%) and the lack of trust among users in algorithms and smart contracts (39%). The interviews also showed the need for regular auditing of industrial procurement in order to maintain high quality standards. Hence, we integrated a supplier preselection in our industrial marketplace concept.

The main potential for combining blockchain with AI was identified for federated learning. Federated learning enables companies to collaboratively train a shared prediction model without having to expose training data. One example for this could be predicting material flows in complex supply chains. In case of a negative event, countermeasures such as hedging risks with derivatives could be initiated in near real-time. Further advantages are seen for adapting procurement processes to current market situations (e.g., customs duties, natural disasters) and the ability to securely store data and decisions during critical decision-making processes in an audit-proof manner.

VI. Conclusion

Current procurement processes are strongly characterized by manual and administrative processes. Hence, they hardly provide easy and automated ways for machines to order and pay for materials and services. In this paper, we present a decentralized industrial marketplace and its implementation in the Hyperledger Fabric framework. The goal of the blockchain-based marketplace is to enable machines to become self-determined market actors, that can order and pay for materials in an automated manner.

First, we conducted a structured literature analysis, which revealed a research gap in decentralized marketplaces in the domain of industrial procurement processes. Based on a detailed requirements analysis, we developed a prototype of a decentralized industrial marketplace using the example of a maintenance process. The prototype was successfully demonstrated to our industrial partners. The experts confirmed the potential of blockchain technology for creating a trusted infrastructure for operational procurement tasks, such as automated ordering and settlement by machines, which improve auditability and traceability for decisions made by machines. The active participation of machines in industrial processes carry enormous potential and the concept could be implemented in the next two to five years. However, social, legal, and economic standards need to be established to enable an effective collaboration between machines and between machines and humans.

Future work should investigate the scalability of the current prototype (i.e., transaction and participant scalability), integrating existing systems (e.g., enterprise resource planning systems), and off-chain data storage and processing (e.g., using the Inter Planetary File System (IPFS)). Furthermore, adopting Directed Acyclic Graph framework (e.g., IOTA and Hedera Hashgraph) that aim to provide the necessary scalability should be investigated.

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