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Jakob Schyga, Johannes Hinckeldeyn and Jochen Kreutzfeldt

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Prototype for a Permissioned Blockchain in Aircraft MRO

Jakob Schyga[1], Johannes Hinckeldeyn[1] and Jochen Kreutzfeldt[1]

1 – Technische Universität Hamburg

Purpose: The paper aims to show strengths, weaknesses and challenges in the application of Blockchain technology for aircraft maintenance, repair and overhaul (MRO). The analysis is based on a prototype of a permissioned Blockchain for the maintenance documentation of aircraft and their components.

Methodology: A prototyping approach is used to gain a deeper understanding of the underlying problems and proposed solutions of applying Blockchain technology to aircraft MRO. The open source platform 'Hyperledger Fabric' and the toolset 'Hyperledger Composer' are used to develop the permissioned Blockchain application. Based on devised use cases the prototype is validated and evaluated.

Findings: Examining the prototype presents opportunities to increase data credibility and efficiency within a decentralized business network through increased transparency, traceability and the use of Smart Contracts. The Blockchain technology could help address challenges in the aircraft MRO industry such as the use of counterfeit spare parts or costly documentation verifications.

Originality: In-depth descriptions of Blockchain use-cases can rarely be found. These are necessary in order to understand the requirements, strengths and weaknesses of using Blockchain in certain business contexts. The development of a prototype furthermore shows a deep insight in the conceptual design, development and usage of Blockchain applications.

Keywords: Blockchain, Hyperledger, Aircraft, Maintenance

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1 Introduction

Blockchain as a technology and as a trend has drawn a lot of attention since its publication by a Satoshi Nakamoto in 2008 (Satoshi Nakamoto, 2008). Although Blockchain has given rise to a myriad of virtual currencies, summarized under the term cryptocurrencies, it has become more than just another means of payment. Basically, the Blockchain is a shared electronic ledger for digital data records that are managed by a number of participants of a distributed peer-to-peer network without the initial requirement of confidence among the members. This means, the innovation of the Blockchain is that transactions between not fully trusted parties can be carried out securely without the necessity of a central institution (Frigden, et. al., 2017). Smart Contracts use this feature to enable the secure and automatic execution of programcode between transaction parties (Buterin, 2013). Currently it is difficult to estimate how big the impact of this technology will ultimately be. Since missing out on the entry into a disruptive technology can lead to a rapid displacement in the market, it is suggested to include Blockchain technology in strategic considerations (Frigden, et al., 2017). Although a number of studies concerning the application of Blockchain technology exists, such as Boyle, et al. (2018), Herwljer, et al. (2018) or Hackius and Petersen (2017), in-depth descriptions of use cases can rarely be found. These, however, are necessary in order to understand the requirements, strengths, weaknesses and challenges of applying Blockchain Technology in certain business contexts. Therefore, this study aims at contributing to this gap through a detailed description of a particular Blockchain use case.

Aircraft maintenance has certain characteristics, due to which the application of Blockchain is suitable, such as a high complexity of processes, networking of several organizations and the demand for mechanisms to increase the efficiency of communication as well as transparency and credibility of data. Resulting from a lack of those aspects, industry-specific issues range from high costs due to missing maintenance records (Canaday, 2017) to an impairment of aviation safety due to the use of counterfeit spare parts (Locatory, 2012). A range of different companies collaborate for maintenance, repair and overhaul (MRO) services of aircraft, starting from maintenance service job shops (backshops) to original equipment manufacturers (OEM) and public organizations for certification and regulation. The International Air Transport Association (IATA) expects substantial benefits from the application of Blockchain to aircraft MRO processes, but also admits the difficulty of realizing this improvement potential (Goudarzi, et. al., 2018). The communication of a large number of companies between the respective often paper-based systems leads in practice to asynchronous data and a relatively small volume of data made available to each company. Data can be used in MRO, for instance for demand forecasting, risk analysis or process improvement. Large companies, in particular OEMs, which also carry out MRO activities, aggregate most of the data and thus gain a strong competitive advantage over small businesses, with the consequence of monopolizing data power (Elliot, 2018). Blockchain technology could help to overcome these issues by offering solutions for a decentralized, comprehensible and immutable database.

This article presents the application of Blockchain and Smart Contracts in aircraft MRO through the development and evaluation of a prototype for the registration of aircraft and their components in a Blockchain. Maintenance activities and ownership transfers are registered in order to provide a complete and transparent documentation by and for the organizations participating in the network. The next section summarizes the current state of Blockchain, while section 3 provides a short overview on the aircraft MRO industry and describes the conceptual model of this research study. The open source platform ‘Hyperledger Fabric‘ and the toolset ‘Hyperledger Composer‘ are used to develop the permissioned Blockchain application. The implementation of the application in Hyperledger Fabric and its way of functioning are described in section 4. Based on devised use cases the prototype is validated and evaluated in section 5. The evaluation contains a discussion of the strengths and weaknesses of the application, its potential impact in the industry and challenges that need to be overcome. The paper closes with some general remarks and further demand of development and research in the area of Blockchain technology.

2 Current State of Blockchain Technology

The Blockchain technology was developed for the original purpose of enabling value transactions between users of a decentralized network securely, directly and trustless and therefore without the need of an intermediary. For the first time the technology was described 2008 in the Bitcoin white paper (Satoshi Nakamoto, 2008) authored by a person or a group under the pseudonym 'Satoshi Nakamoto'. The identity behind the pseudonym has been unknown to the public, in spite of multiple speculations. This original type of Blockchain technology for money transactions is some-times called first generation of Blockchains (Cummings, 2019). The Blockchain technology is not a monolithic invention as such, but rather a meta-technology combining a number of different technologies, which were already invented and known at the time the Bitcoin whitepaper was published. It integrates previously known technological components such as peer-to-peer technology, asymmetric cryptography, digital signature, Merkle-trees and a consensus algorithm such as proof-of-work into a common concept (Narayanan and Clark, 2017). Figure 1 shows an abstract of a generic Blockchain data structure. The Blockchain data structure links transactions between two parties efficiently and in a verifiable way (Iansiti and Lakhani, 2017). Transactions are linked by so-called hash references inside of a block. The blocks additionally contain a timestamp with the time of block creation, its own cryptographic hash value (Block ID) and the Block ID of the previous block, therefore building a chain of blocks. The transactions and blocks are created and validated by the nodes communicating through a peer-to-peer network (Drescher, 2017). In Bitcoin technology the proof-of-work algorithm is used to build a common consensus. If the proof-of-work algorithm is applied, a block contains additionally the difficulty for block creation and a random number called nonce. Before Bitcoin, it has not been possible to conduct transactions between distributed individuals without a verifying central control instance, such as a central bank. Today, also other consensus algorithms are used such as proof-of-stake or practical byzantine fault tolerance (Hinckeldeyn, 2019).

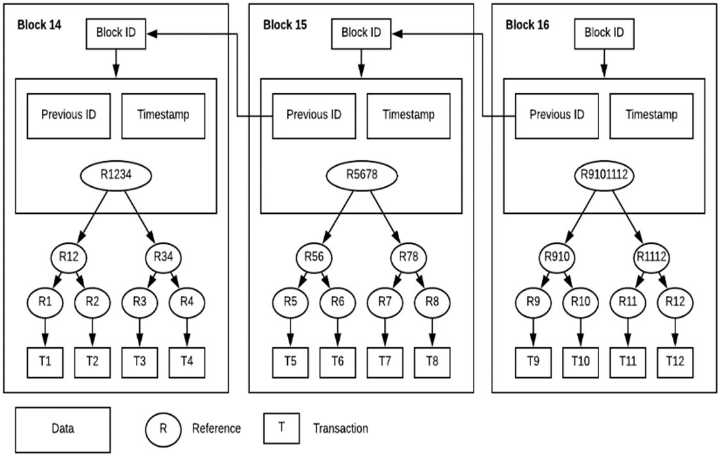

Figure 1: Abstract from a Blochain data structure

Since the creation of Bitcoin, Blockchain technology has evolved. A second generation of Blockchain emerged with partially extended functionality. In 2013 Vitalik Buterin proposed Ethereum, which expanded the Bitcoin technology by the functionality of Smart Contracts (Buterin, 2013). These contracts were proposed already in 1996 by Nick Szabo (1996) but were first made possible by Ethereum in 2015 as software scripts, running on a Blockchain (Tual, 2015). This means that the transactions run a computer program with the same certainty and trust like a Bitcoin transaction. Hence, it allows the automatic execution of programmed agreements between distributed transaction parties within the Blockchain. The innovation of Smart Contracts created a large number of use cases that go far beyond cryptocurrencies. Various companies in industry-specific consortia develop use

cases and solutions, suitable to be implemented using Blockchain technology (Frauenhofer-Gesellschaft, 2017, Chamber of Digital Commerce, 2016). Bitcoin and Ethereum are public and permissionless Blockchain networks, which means that anyone can join the network with more than one account, view its information and use its functions. However, for the business contexts there are usually requirements to comply with confidentiality of data, identification of the participants and network performance.
This led to a third generation of Blockchain technology, which integrates better the requirements and systems of existing companies. In contrast to public Blockchains, these platforms are not necessarily open to everyone and provide other architectures and consensus algorithms for better scalability and data protection. For example, Hyperleger Fabric is a private, permissioned Blockchain platform, developed especially for the use in business networks, offering a modular architecture and a high degree of flexibility, confidentiality and reliability (Hyperledger Fabric, 2019). Several fields have been identified for a suitable application, such as internet of things, energy supply, the insurance sector or the supply chain (Herwljer, et al., 2018. Brandt, et al., 2018, Schlatt et al. 2016).

3 Conceptual Model

Aircrafts are the most complex machines produced in series and therefore represent substantial investment and operational costs for the owner. An aircraft can only make profit while in operation. It is therefore necessary to limit ground time to the bare essentials and to allocate aircraft a tight flight schedule. Since maintenance activities are performed only on ground they are planned in detail and if possible follow the operational breaks according to the flight schedule. In the event of unplanned downtime, it may be a problem to provide a replacement aircraft at the respective airport. This results in irregularities or failures in flight planning, which entail high follow-up costs. The objective of aircraft MRO is to maintain the airworthiness of aircraft or aircraft components through planned activities of regular maintenance, inspection and overhaul, or to restore them through repair.

As the survival of passengers is directly ensured by the safety of the systems, the processes of aircraft maintenance are strictly regulated and monitored by regulatory authorities such as the European Aviation Safety Agency (EASA). Within the European Union, the requirements and procedures for design, manufacture and maintenance are set by EASA as part of the so-called Implementing Rules. Maintenance operations are defined by the Implementing Rules Continuing Airworthiness (IRCA) in Part 145 (EASA, 2014). The American equivalent to ICAR Part 145 is the Federal Aviation Regulation for Repair Stations (FAR 145). Since the American structures were adopted or used by EASA, the regulations of the USA are very similar to those of the European Union (Hinsch, 2017). Due to the strict regulation of the aviation industry, the business processes differ only slightly. Based on the IRCA, the generic process diagram in Figure 2 is considered in order to illustrate business processes and how they are interconnected between organ-izations involved in aircraft maintenance.

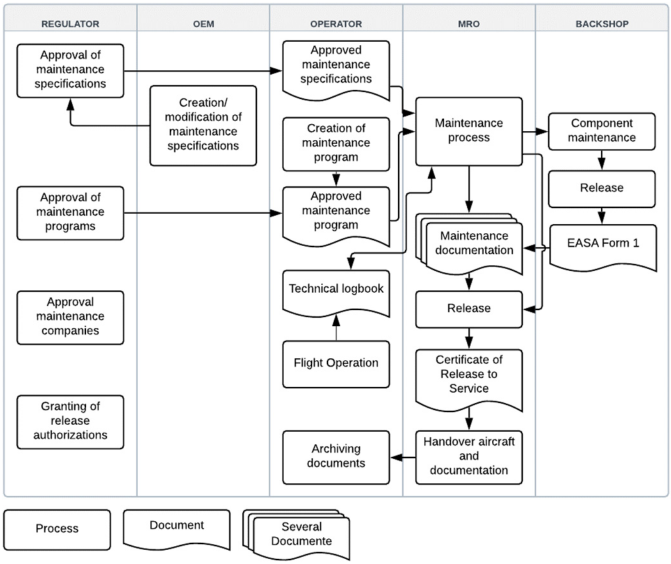

Figure 2: Processes in aircraft MRO

OEMs, MROs and backshops must be certified by the regulatory authority and maintenance activities may only be carried out in accordance with approved maintenance specifications. Planned maintenance activities are scheduled by the operator in a maintenance program, which is also to be approved by the regulatory authority. Furthermore, the regulatory authority grants authorizations for the release of components and aircraft. The OEM prepares maintenance specifications for each aircraft model by describing the maintenance activities and defining the maintenance intervals for the individual components. The aircraft operator is obliged to create a maintenance program based on information provided by the OEM. In the maintenance program, all maintenance activities of aircraft components with their planned intervals are listed. Functional failures called findings as well as their rectification are documented in the technical log book of an aircraft. The aircraft operator is also responsible for archiving the maintenance documents. The maintenance process is triggered either by specifications of the maintenance program or by findings that have occurred. Due to the high complexity of the products various parties are involved in the maintenance of an aircraft. Maintenance companies (MROs) are responsible for the maintenance of the operator's aircraft. In particular, the maintenance of complex components such as engines maintenance is carried out by specialized third-party workshops called backshops. For repaired aircraft and certain components, approval must be granted again by a certifying officer approved by the regulatory authority. As a result of a successful release, the so-called EASA Form 1 will be issued for components and the Certificate of Release to Service (CRS) for aircraft. The aircraft is then handed over to the operator, including all incurred maintenance documents. (Hinsch, 2017, EASA, 2014)

The Blockchain network of the conceptual model is mapping the maintenance network consisting of an arbitrary number of directly or indirectly in the maintenance involved organizations. In the network participating organizations have to be categorized according to their roles in order to enable different permissions. In addition to the regulatory authorities, OEMs, aircraft operators, MROs and backshops, component suppliers are included into the model. Each organization provides one or more participants to the network. The participants are grouped according to their role into Supplier, OEM, Operator, MRO, Backshops and Regulator. The possibilities of interaction between participants within a maintenance network differ depending on their role. Figure 3 shows the section of the UML class diagram referring directly to the participants.

Aircraft and aircraft components (Parts) are registered in the Blockchain data structure and status changes such as the transfer of ownership, execution of flight operation or conduction of MRO activities are recorded. Due to the properties of the Blockchain technology a ledger of transactions is created containing the full history of the objects conditions without the need for a central instance. The states of the objects, such as the certification can be verified by the immutable history data and filtered through database queries. Methods are completely transparent within the network, but can only be processed by authorized network participants.

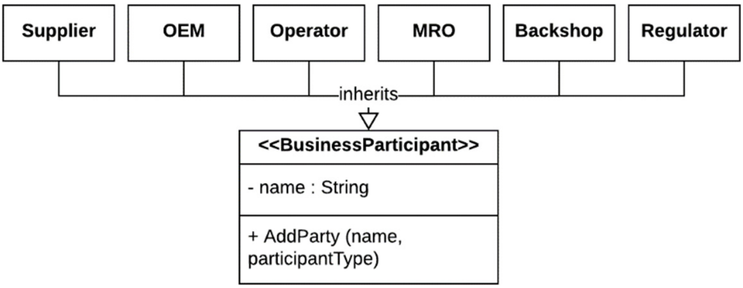

Figure 3: Class diagram participants

In particular, for registering and changing the state of assets, the secure allocation of the physical objects to the digital entries in the Blockchain data structure must be ensured. In order to prevent deceptive action, the responsible person has to digitally sign each transaction. Manipulation at the entry of data cannot be ruled out on the program side even with centralized systems.

The tangible assets Aircraft and Part define two basic levels of the program, while Aircraft are composed of Parts. Figure 4 shows the corresponding section of the class diagram, with the methods and attributes being hidden for reasons of clarity. The classes on the left are assigned to the Aircraft level and the ones on the right to the Part level of the program. Participants are enabled to create and delete, send and receive objects, to change property rights and issue or withdraw airworthiness. Furthermore, the installation and removal of parts in an aircraft can be registered. In order to fulfill the main function of documenting the maintenance history, the classes Finding and Report are defined.

A Finding contains information on damage or anomalies that have occurred to the physical object and must therefore always be assigned to an object in the program, whereby several Findings can be assigned to one object. The attributes store information about the documenting organization and person, the date of occurrence and a description.

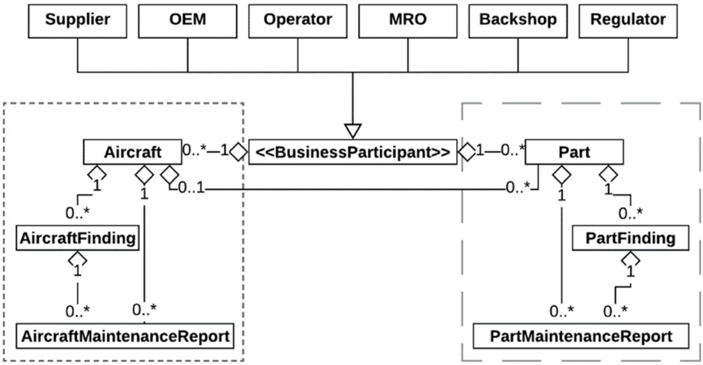

Figure 4: Abstracted class diagram

A Report describes the execution of maintenance activities. Similar to Findings, a Report is always assigned to one tangible object, whereby one object can be assigned to several reports. A Report can be declared as either a routine task or a non-routine task, while in the case of a non-routine task, a Report usually also refers to a Finding. A Report contains the performing organization and person, execution date and a description of tasks. In addition, the mileage of the object at the time of execution is stored.

4 Implementation

The use case of MRO possesses characteristics, which constrain the selection of an appropriate Blockchain framework. The industry-specific requirements for data confidentiality and safety make it particularly important to draw attention to the identification and permission of network participants. In conventional Blockchain technology like Bitcoin or

Ethereum different branches of the Blockchain data structure occur and the proof-of-work algorithm serves to agree on a common version. However, this type of consensus algorithm is not capable of reaching finality on transactions, which means that it is increasingly unlikely over time but possible to change transactions after execution. As Hyperledger Fabric uses a different transaction flow and consensus mechanism it allows for a higher performance in lower scaled networks and it is capable of reaching finality of transactions, making them impossible to be changed or reversed (Hinckeldeyn, 2019). Since maintaining consensus between the ledger copies in Fabric does not require proof-of-work, no cryptocurrency is needed as an economic incentive for block creation (Sajana, 2018). Furthermore, Fabric is providing a modular architecture that allows for high resiliency and flexibility to adapt the network according to the specific use case requirements (Hyperledger Fabric, 2019).

The modular design of Hyperledger Fabric for business context is leading to great popularity of the platform. Forbes published a list of 50 companies with a minimum revenue of one billion dollars that are leading the way in adapting decentralized ledgers to their operating needs. 22 of the 50 Companies, from Amazon to Walmart are dealing with Hyperledger Fabric (Del Castillo, 2019).

Due to its modularity, confidentiality and performance characteristics, Hyperledger Fabric is currently the most suitable Blockchain technology capable of running Smart Contracts to implement the previously described model. Furthermore, all Hyperledger projects are open source software under open governance of the Linux Foundation, so everyone can see, use, copy and contribute to the program code (Dhillon et al., 2017).

A ledger in Fabric is composed of a database called World State and a Blockchain data structure. The database stores the states of participants and assets. Assets are tangible goods, such as aircraft, or intangible goods, such as maintenance records. A state of the asset Aircraft for instance could be the name of the owner. The Blockchain data structure is containing the preceding transactions, which usually lead to changes of the World State such as send Aircraft to initate the transfer of an aircraft's ownership. The World State can be calculated at any time from the Blockchain data structure and thus be verified. Figure 5 illustrates the relationship between the ledger, World State, and the Blockchain data structure in Fabric. The ledger is composed of the World State and the Blockchain data structure, whereby the Blockchain data structure determines the World State. The ledger is managed by Smart Contracts called Chaincode in Fabric. These contain asset definitions as well as the business logic for changing those assets. Nodes in Fabric are assigned to an organization and are distinguished according to their function in peers, ordering-service-nodes called orderer and applications. Typically, every business would be a separate organization in Fabric and would contribute to the network with their own peers, ordering-service-nodes and applications. In order to save resources, it is also conceivable that several, in particular smaller companies join together to form a common organization in Fabric.

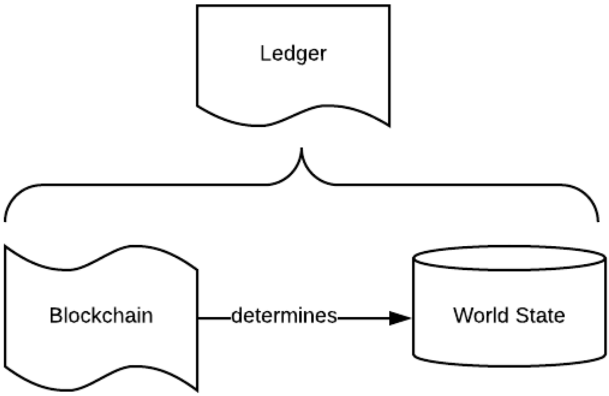

Figure 5: Components of a Ledger in Fabric (Hyperledger Fabric, 2019)

Peers are the most fundamental building block of the network because they manage the copies of the ledger and Chaincode. Applications are users of the network which communicate with it through transactions while the orderer is responsible for arranging transactions into blocks. The only mechanism of interaction with Chaincode is through transactions invoked by applications.

The transaction flow is illustrated in Figure 6. After connecting to the peer (1) the application initiates the transaction flow by creating a transaction proposal. The application sends the transaction proposal to the peers of the network (2), which execute it independently by invoking the Chaincode to generate a transaction response (2.1 and 2.2). The proposal response is not applied directly to the ledger, but only digitally signed by each peer and returned to the application (3). As soon as the application has received sufficient identical transaction responses, they are sent to the orderer (4), who

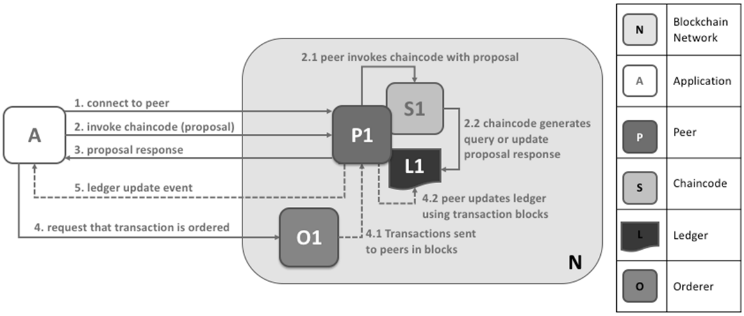

Figure 6: Transaction flow in Fabric (Hyperledger Fabric, 2019)

is then sorting the transactions mechanically into a block and forwarding it again to the peers (4.1). The peers process the obtained block independently. After each transaction has been verified, the block is added to the Blockchain data structure and the World State updated (4.2). Failed transactions are marked as such and are also added to the ledger as part of the block, but do not affect the World State. Finally, the applications are notified of the success or failure of the transactions (5).

To identify them, network participants in Fabric are issued a digital certificate, and a cryptographic key pair by an organization-owned component called Certificate Authority. Another component called Membership Service Provider assigns roles and organizations to the identities and authenticates them as members for the use of the network. MSPs provide dynamic membership by adding and removing access permissions in a decentralized way to ensure long-lasting network integrity.

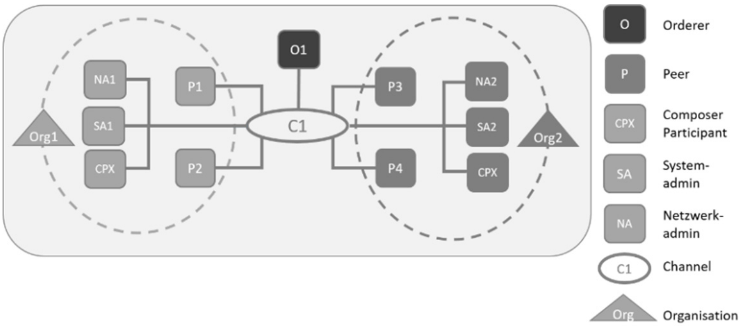

Figure 7: Structure of the designed fabric network

To support the development of Blockchain applications with Fabric, Hyperledger Composer was developed as part of the Hyperledger project. Composer is a collection of tools allowing the creation of Chaincode in a structured and clear logic as well as the subsequent provision in a Fabric network (Dhillon et al., 2017). One of the tools is the browser-based user interface Hyperledger Composer Playground, which is used to test the functionalities of the program. The programming in Composer is carried out on the basis of assets, participants and transactions. The program code is written in several files with different purposes. In the model files the fundamental components are defined as participants, assets and transactions. Methods are written as transactions in script files using JavaScript. Restrictions are defined in an access control file to ensure that only authorized network participants can initiate appropriate transactions. Furthermore, separate query files are used for database queries. From the separate files of a program, a Business-Network Archive (BNA)-file is generated, which is then provided as Chaincode to an existing Fabric network.

The designed Fabric network is illustrated in Figure 7. For a real use case, the Fabric network would be formed by a consortium of several companies, and optimally each participating company would form an organization in Fabric. The designed Fabric network is formed by the two organizations Org1 with the peers P1, P2 and Org2 with P3, P4 and a central orderer O1. The affiliations of the network components to the organizations are illustrated by the dashed circles. System administrators SA1 and SA2 were added to deploy the Chaincode on each organization's peers and to create the network administrators NA1 and NA2. The organizations can then use the rights specified in the deployed Chaincode to create further network participants CPX of any role according to Figure 3 and link them with identities. The nodes NA, SA and CPX represent the users of the network who in practice communicate with it via client applications. Regarding the given use-case CP1 could be the MRO-company Lufthansa Technik and CP2 the Airline Lufthansa, forming a common organization Org1 and contributing to the network by providing peers and orderer. A second organization Org2 could be formed by the OEM-company Airbus and the Supplier General Electric.

In the present Fabric network, there is a single orderer and thus a partial centralization of the network. A more decentralized approach could be realized by each organization providing an ordering-node, which form a common consensus on the Kafka protocol. Kafka uses Apache Kafka, an open-source stream processing platform that enables processing of continuous data streams of structured data (Apache, 2017). All orderers would send incoming transactions to Kafka and receive transactions in the same order as the others. (Hyperledger Fabric, 2019)

5 Evaluation

In order to validate the investigation model, case studies were designed and carried out. Subsequently the model's strength and weaknesses were evaluated based on the conducted case studies. Furthermore, current issues in aircraft MRO industry to which the application of a Blockchain network could contribute to the solution and challenges that need to be overcome to reach a use in practice are shown.

5.1 Validation

To consider the network size and complexity of processes in the evaluation, four case studies with two different numbers of participants and two different maintenance scenarios were designed.
Network A is a small network, consisting of one operator, one MRO, one regulator and three backshops without direct competition. The main purpose of the network is to record the history of maintenance activities rather than tracking property rights. Figure 8 illustrates the business network on the application level. The whole Fabric network infrastructure is built by the nodes previously described, while the participants such as MRO A or Operator A are the Composer participants CPX according to Figure 7 and are assigned to one of the organizations Org1 or Org2.
Network B is a medium-sized network consisting of a total of 18 participants for the tracking of maintenance activities and property rights. For each role, with the exception of the regulator, there are competing participants.

Based on the same base configuration of assets (one Aircraft containing four Parts), two hypothetical maintenance scenarios were designed. The scenario routine maintenance describes the execution of maintenance activities as part of an A-check. First, the aircraft to be inspected is handed over by an aircraft operator to the responsible maintenance company, which detects damage by inspecting the structural elements winglet and flaps. The findings of the winglet will be fixed during the check and the re-

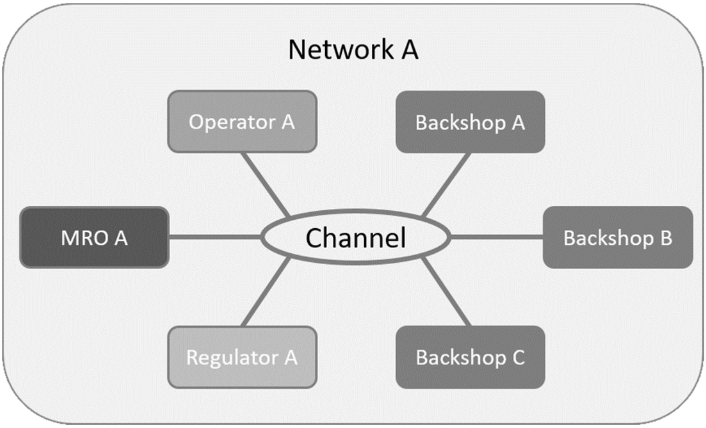

Figure 8: Illustration of business network A

pair of the flaps will be postponed to the following check. Subsequently, the aircraft is returned to the original aircraft operator.

The second investigated scenario is a non-routine maintenance in which a bird strike during flight operation results in findings and the need to carry out maintenance. The aircraft operator ascertains that the aircraft has been taken out of operation, declares it non-airworthy and hands it over to a maintenance company. The maintenance company detects damage to a turbine and to a hydraulic pump. The hydraulic pump has to be replaced while the turbine is declared non-airworthy and transferred to a backshop for repair. Since the maintenance operation does not keep the hydraulic pump in stock, it is ordered by a supplier and then reinstalled by the maintenance company. The turbine is repaired by the backshop, airworthiness is granted by the regulatory authority and the turbine is sent back to the maintenance organization for installation. After a test flight is carried out, the regulatory authority issues a new airworthiness certificate. Ultimately, the aircraft is returned to the original aircraft operator.

The pairwise combination of the scenarios with the networks A and B result in four case studies. The designed case studies were successfully carried out with the developed prototype and therefore mapped in the Blockchain data structure. For the scenario of routine maintenance, eight and for non-routine maintenance 24 transactions were executed in the correct sequence by the different participants. The executed transactions are stored in the Blockchain data structure resulting in a new configuration of objects and their states. Figure 9 shows the configuration of the objects before and after the non-routine scenario was carried out. Each block represents an object in the business network and the connections between the blocks correspond to the assignment between the assets. Within the blocks, attributes of the objects relevant for the representation are entered. Figure 10 shows the transactions performed by the participants in order to carry out the scenario.

The fulfillment of the network requirements for identification and authorization of network participants and dynamic admission restriction could be confirmed. The decentralization of the network infrastructure was limited by the central ordering service and the fact that the network infrastructure was formed by only two organizations, but it was shown in which way a decentralized network could be realized. The transaction confirmation time and transaction throughput cannot be appropriately quantified using the developed model. However, with a similar Fabric setup a benchmark analysis from Baliga et al. (2018) shows a linear transaction throughput with a transaction confirmation delay time of up to 2 seconds at an increasing input load of up to 1000 transactions per second. These performance parameters are more than sufficient for the considered use case. Furthermore, the fulfillment of the application level requirements for the digital registration of aircraft and components to store their states and status history, the transparency of the data and querying of data in a Blockchain network was successfully demonstrated. On the Smart Contract-layer the same business logic could be implemented using other programmable Blockchain platforms such as Ethereum or Hyperledger Sawtooth. However, the consequences for the properties of the network would change based on the chosen Blockchain technology.

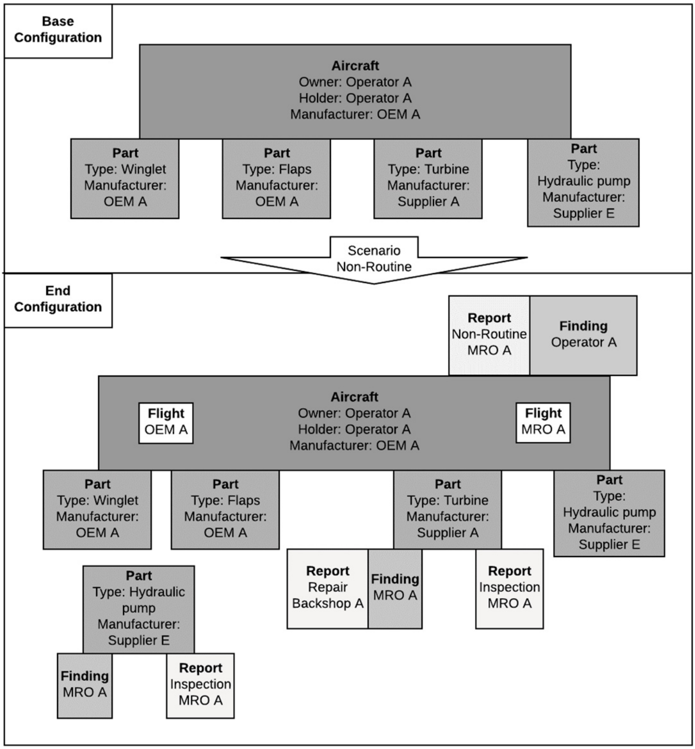

Figure 9: Base and end configuration of the objects after the non-routine scenario

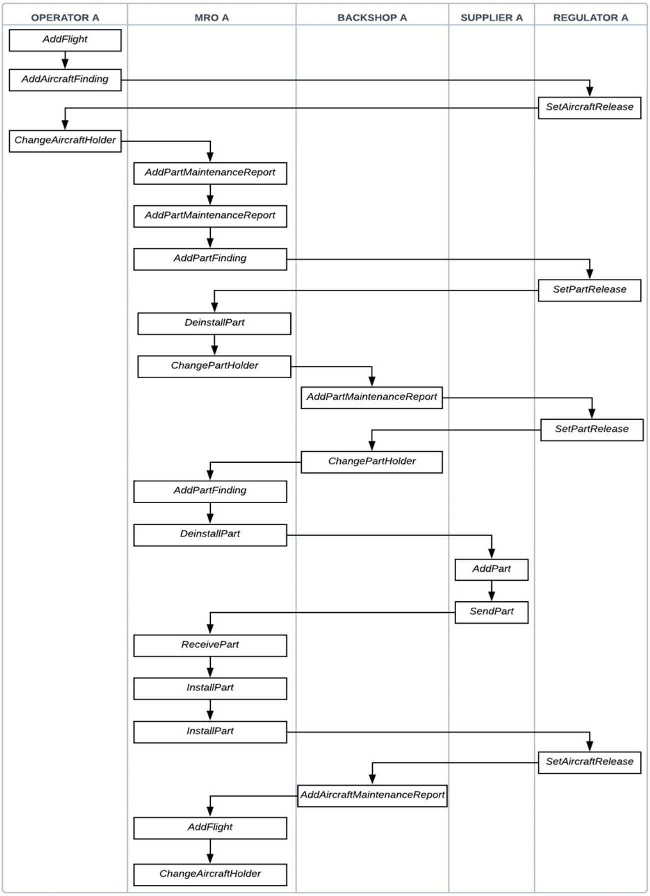

Figure 10: Transactions performed for the non-routine maintenance

5.2 Strengths and weaknesses

In the following, the strengths and weaknesses of using a decentralized network according to the developed prototype will be discussed.

The power over the data in a decentralized network is distributed among the participating organizations. The developed Fabric infrastructure is built on two organizations and a single orderer and is thus partially centralized. A more decentralized approach could be realized by assigning each participant of the network to a separate organization, providing its own peers and orderers. Nevertheless, the distributed power over the data leads to a higher willingness of the organizations to share their data in order to benefit from the network and from the data of other organizations. The additional data an organization obtains from participating in the network may contribute for instance to demand forecasting of spare parts, risk analysis, or product and process improvement. Each network participant is required to contribute data to the network, as one participant would otherwise not benefit others, but increase their risk. The larger the network and the higher the amount of competing participants the bigger is the risk of sharing data. This is particularly evident when comparing network A and network B from the carried out case studies.

Fabric offers the functionality of different channels to keep transactions in a shared network secret. A channel is formed by peers, applications and orderers and serves for the complete decapsulation of ledgers and Chaincode. The nodes can be assigned to multiple channels. Only the nodes of a channel are involved in the consensus building of the respective ledger and can thus see Chaincode, ledger and transactions. Channels could therefore protect data between competing organizations and only provide it to the participants desired. For smaller networks channels are easy and logical to implement. With reference to the use cases, sensitive data from competing backshops Backshop A and Backshop B could keep their data secret from each other and still make it available to the rest of the network. Figure 11 illustrates the use of channels for a given network. All network participants form a common channel (Channel A). The competing backshops also each form a separate channel (Channel B and Channel C) with the other network participants. To maximize the overall value of the network, without penalizing individual network users by the risk of external data usage, compromises must be made between the participating organizations in order to agree on channel configuration and sharing of data. In practice, cooperation between often competing companies with different interests must be formed in order to define common goals and requirements.

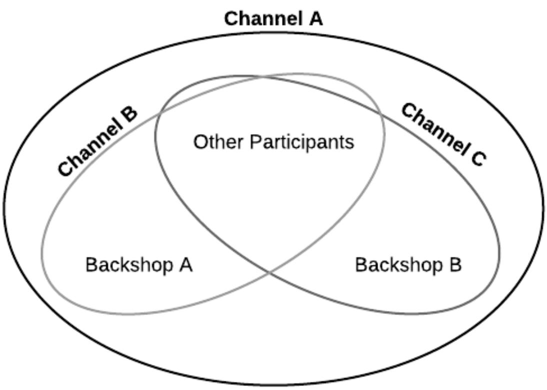

Figure 11: Confidentiality of sensitive data through the use of channels

Applying a Blockchain network according to the prototype, certain intermediaries could be avoided and as a result process time and costs be saved. By reducing process times, the entire maintenance process can be accelerated, thereby reducing the cost-intensive downtime of aircraft. Intermediaries, in particular, are auditors of documentation for the maintenance network, e.g. custodial employees of the regulatory authorities or document inspectors of an aircraft operator at an aircraft overtake.

Due to the distributed data and consensus building, there is a very low risk of data loss due to malfunction or hacker attacks and a high synchronicity of data between the organizations. On the other hand, the process of distributed consensus building requires a high time for transaction confirmation and low transaction throughput, compared to centralized systems, especially for large networks.

From the properties of the Blockchain data structure and the distributed consensus building results a high change inertia of the network and the irreversibility of transactions. This effect increases with the size and decentralization of the network. It follows a high security against data manipulation, since once entered transactions cannot be removed or changed without a common consensus. Together with the data transparency within the network, there is a good traceability of all activities of the participant in the networks. Traceability in the case of aircraft MRO can for instance contribute to facilitate rapid problem identification and elimination in case of premature component failure. On the other hand, the irreversibility of transactions limits the flexibility of organizations, as erroneous or erroneously submitted transactions generally persist. The program code of the developed prototype therefore provides transactions to reverse the effects of registered transactions in the World State.

The implementation of Smart Contracts in a distributed network enables the automation of process execution and thus also a shortening of process times by avoiding human labor with a high system availability and reliability of function execution. Due to the inertia of change and the fact that the programmed code of Smart Contracts is executed exactly as it was instructed, great care must be taken to understand how the code can affect network subscribers. Therefore, experts and adequate tools for the programming of Smart Contracts are needed.

5.3 Issues in Aircraft MRO

In the following, two selected issues in the aircraft MRO industry are shown and explained in which way a decentralized network according to the developed prototype could contribute to their solution.

Due to the complexity of aircraft and the high costs of spare parts and certifications arise risks of flight safety through the use of counterfeit spare parts. Counterfeit spare parts are components that have not been approved by the aviation authorities often made of inferior materials or with exceeded lifetime. Monitoring the authenticity of spare parts is problematic because of the component complexity, especially when the maintenance processes have been outsourced to MRO operations abroad (Locatory, 2012). In 1989, Partnair Flight 394 crashed due to counterfeit components on the route from Oslo to Hamburg, leading to the deaths of all 50 passengers and 5 crew members (Luedemann, 1996). To guarantee the authenticity of a part it is essential to ensure that physical parts are correctly linked to their digital counterparts. An object therefore has to be linked to a unique identifier, which is printed, embossed or attached as a tag to the object. Balagurusamy et al. (2019) explain how an identifier, such as the object's surface structure, can be used to securely link an object to its properties asserted in a trusted database. The traceability of the transaction history with full data transparency could help to reduce the use of counterfeit spare parts. If a counterfeit component were to be installed in an aircraft, then the entry of the component is already to be falsified. All parties in the network would be able to review the transactions and assign responsibilities. If the component turns out to be a counterfeit, the guilty party could be easily and quickly identified. A prerequisite for this is that the storage and certification of the aircraft and components in the Blockchain data structure is recognized by the legislator.

The cost of transferring ownership of aircraft and components between aircraft operators in commercial aviation is approximately one billion dollars per year according to Canaday (2017). In addition to the storage, management and transport of records, there is a significant cost component in the verification of maintenance records. The verification of maintenance records is necessary to ensure the safety of the aircraft and to meet regulatory requirements. Missing, incorrect or incomprehensible records lead to costly rework and thus delays. (Canaday, 2017)

The use of a decentralized network according to the developed prototype could increase the credibility and traceability of maintenance records. During the transfer an aircraft's ownership, the inspection effort and therefore the costs of document verification could be reduced. Furthermore, the distributed nature of the Blockchain minimizes the risk of data loss, which could also reduce rework due to lacking records. If the old and new owners are located in a common network, seamless data transmission and utilization could be realized.

5.4 Challenges

In order to enable an efficient application of the Blockchain technology, interoperability is required to easily integrate the various systems (Banerjee, 2018). The largest producer of software solutions for enterprise software SAP is actively involved in the integration of Blockchain applications into their existing systems and has been a premium member of the Hyperledger Foundation since March 2017 (Hyperledger, 2017). In October 2018, Hyperledger's subproject Hyperledger Burrow enabled the provision of Ethereum Smart Contracts on Hyperledger Fabric (Ledger Insights, 2018). Another recent project of the Hyperledger Foundation is Hyperledger Quilt for the interoperability of Blockchain systems through the application of a payment protocol (Hyperledger Foundation, 2018).

Furthermore, challenges arise from uncertainties due to a lack of regulations. Currently, the legal implications of Blockchain data are not clearly defined. It is necessary to explore how existing contract law affects Smart Contracts and to adjust legal procedures to properly manage Smart Contracts. A prerequisite for the development of legal regulations and the creation of interoperability is the introduction of standards for designations and descriptions in order to facilitate a smooth communication and to prevent misunderstandings (Banerjee, 2018, Chamber of Digital Commerce, 2016).

For the creation of standards and legal regulations and the overcoming of technological challenges the inter-organizational collaboration of companies, research institutes and legislators is required. While these challenges are likely to be overcome in the foreseeable future, the need to co-operate with competing companies in a common network presents a challenge with an uncertain outcome.

Further uncertainties arise because there are hardly any practical applications in the industry or experts whose application experience could benefit a business network. The introduction of novel systems within the organizations is generally associated with a great deal of time and expense. The systems therefore have to last for a longer period of time to recoup their costs. However, there is a great deal of long-term planning uncertainty due to the changing nature of the industry, the participating organizations with their relations and needs, legal regulations and in particular the technology. A technology implemented today could already be obsolete in a few years' time.

6 Conclusion

Blockchain technology was first described in the end of 2008 and the Hyperledger project is existing since december 2015. Therefore, it is comprehensible that at the time there are various technological, regulatory and organizational challenges ahead. It is important to educate about the technology, its application and potentials without fanning false hopes. It will be necessary to further identify opportunities and risks through the development of investigation models and testing of applications. The present work contributes to this by providing a prototype solution for the MRO-industry, demonstrating its development and analyzing the applicability.

Based on an analysis of the processes in aircraft MRO a conceptual model was developed. The program code was then authored using the Hyperledger Composer toolset, deployed on a Hyperledger Fabric network, and validated by case studies. The analysis of the study model shows a considerable potential of the technology to increase the efficiency of an MRO network through credibility, traceability and transparency of the data, with high reliability and system availability, especially for larger networks with a high complexity of process flows. The usual high costs in the aviation industry due to warehousing, document checking and downtime of aircraft could potentially be reduced and the safety of the aircraft increased by avoiding the use of counterfeit spare parts.

Businesses could start using the technology for non-sensitive data to demonstrate the security and operational efficiency of the systems by first deploying applications within their enterprise and then extending them to cooperating companies. Finally, the development of the Blockchain's full potentials as an infrastructure technology requires a critical mass of key players in the market. While the MRO industry has lagged behind other industries in terms of IT deployment, it could be a trailblazer in the application of Blockchain technology because of the highly regulated and interconnected nature of maintenance for small-scale, high-complexity products. Adoption of an application for aircraft MRO is conceivable in similar industries that rely on complex fleet maintenance with several parties involved, such as shipping or rail.

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