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Blockchain Based Transactions Between Indian Air Force and Its Aerospace Defence Company

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Abstract

The use of Blockchain technology has gained widespread acceptance across various fields, including cryptocurrencies, supply chains, healthcare, and finance. It has proven to be particularly innovative when applied to the supply chain industry. Numerous cases have demonstrated how blockchain technology can unify diverse stakeholders within a large supply chain on a single platform, ensuring transparency and creating a trustless environment. This is achieved through a shared, distributed, and immutable ledger that facilitates transaction recording and asset tracking within a business network. In this project, we propose applying Blockchain technology to transactions between the Indian Air Force (IAF) and Hindustan Aeronautics Limited (HAL). Aircraft components frequently move from IAF to HAL for repair and maintenance, changing hands among various departments involved in servicing these components. The proposed blockchain-based architecture for transactions between IAF and HAL aims to enhance transparency and security, establish a trustless environment among all stakeholders, and enable them to optimize their operations. This improvement is expected to reduce the time an aircraft spends on the ground due to unserviceable components.

Keywords: Blockchain, Hyperledger, Aircraft, Component, Tracking, Asset

1. Introduction

The Indian Air Force (IAF) is the fourth largest air force in the world and is responsible for safeguarding India's airspace. The IAF operates and maintains a diverse fleet of aircraft, including fighters, transport aircraft, and helicopters. While field units, known as Operational Units (Ops Units), handle the operation of these aircraft, major repairs, maintenance, and overhauls are conducted by Hindustan Aeronautics Limited (HAL), a Defence Public Sector Undertaking (DPSU) in India. Consequently, aircraft and their components are transported to various HAL divisions for repair and maintenance as needed.

In the current transaction system between the Indian Air Force (IAF) and Hindustan Aeronautics Limited (HAL), faulty aircraft components from the IAF are sent to HAL for repair, maintenance, and servicing. Since the IAF Operational Units (Ops Units) and HAL

Divisions are typically not co-located, the IAF has established a liaison element known as the Air Force Liaison Establishment (AFLE) at HAL Divisions to facilitate better coordination.

When a component becomes unserviceable (U/S), it is dispatched from the Operational Unit (Ops Unit) to the Air Force Liaison Establishment (AFLE), which then forwards it to Hindustan Aeronautics Limited (HAL) for repair. As the component moves from the Ops Unit to AFLE, then to HAL for repair, and finally back to the Ops Unit as a serviceable (S) item, it passes through various sub-departments within both AFLE and HAL. These departments handle tasks such as receipt and dispatch, inspection, storage, repair work on test benches, and associated documentation like generating vouchers, receipts, and invoices. Thus, the equipment changes hands multiple times during this process.

A significant challenge in this system is tracking aircraft parts across organizational boundaries throughout the entire chain. The current tracking process is time-consuming and prone to inaccuracies due to numerous human interactions via phone calls or in person. Sahay & Anant (2012) suggest using the Internet of Things (IoT) with radio-frequency identification (RFID) tags to streamline part tracing and tracking, enhancing supply chain efficiency. However, issues related to information security and access rights remain unresolved. The absence of an optimal data management solution impacts maintenance service planning and stakeholder efficiency. Delays in aircraft maintenance services due to inadequate information flow can affect the operational readiness of the IAF, leading to Aircraft On Ground (AOG) situations due to unserviceable components awaiting repair at HAL.

The current manual process presents several issues, including difficulties in tracking components, a lack of trust among stakeholders, and delays in component repair due to poor planning and foresight regarding manpower and spare parts availability at HAL. Additionally, each stakeholder maintains independent records, increasing the risk of mismatches and conflicts. These issues lead to delays in receiving serviceable components back at the Ops Unit, resulting in extended aircraft downtime.

To address these problems, we propose implementing a blockchain-based transaction system to manage the entire flow of components, from dispatch from the Ops Unit as unserviceable to receipt back at the Ops Unit as serviceable. This system will bring all stakeholders onto a common platform, with transactions recorded on a Distributed Ledger only after obtaining consensus from the majority of stakeholders. This approach will create a trustless environment without a central regulatory authority, resolving record mismatches, and enhancing accountability and transparency in equipment handling, ultimately reducing aircraft downtime at the Ops Unit.

2. Related Works

This section aims to illustrate the recent works in Blockchain technology implications and implementation in various fields, particularly in the aviation industry with a focus on secure asset tracking.

2.1. Blockchain Technology

Blockchain technology gained significant attention following Nakamoto's (2008) groundbreaking research, which introduced a peer-to-peer electronic cash system that allows online payments to be sent directly from one party to another, bypassing intermediaries like financial institutions. This innovation led to the emergence and widespread acceptance of various cryptocurrencies, such as Bitcoin and Ethereum. However, blockchain technology extends beyond cryptocurrencies and has numerous other applications.

Blockchain is a decentralized digital ledger technology that enables the recording of transactions across multiple computers, or nodes, securely and transparently. Transactions are managed through consensus mechanisms and encrypted for security. Masood et al. (2018) highlight that distributed ledger technology (DLT) serves as the foundational framework for many blockchain-based systems. In a blockchain system, data records are referred to as blocks. Each block's hash value, calculated using a hashing algorithm, is included in the data of the subsequent block. This linking of blocks creates a chain known as a blockchain. These interconnected chains are also referred to as ledgers. Zhali et al. (2019) explain that blocks and chains form a blockchain network, with transactions processed and verified autonomously through cryptography. The ledger's consistency and agreement among participants are achieved through consensus mechanisms, which enable decentralized decision-making regarding the validity and order of transactions or events. Various consensus mechanisms, such as Proof of Work (PoW), Proof of Stake (PoS), and Byzantine Fault Tolerance (BFT), are available, with their suitability depending on the specific use case.

Blockchain systems can be classified as either public or private. According to Falazi et al. (2019), the primary distinction lies in the membership and authorization required to participate in the network. A public blockchain is open and permissionless, allowing anyone to register and join the network without prior approval. In contrast, a private blockchain requires participants to have membership rights to access and contribute to the network.

2.2. Blockchain in aircraft-related use cases

Wang et al. (2019) examine the current state of airworthiness assurance for domestic Chinese aircraft equipment, highlighting risks in airworthiness under existing conditions. They suggest that employing Blockchain technology, particularly for airworthiness traceability of aircraft materials, can enhance the airworthiness throughout the entire lifecycle of aircraft equipment. Madhwal & Yash (2020) propose using a private, permissioned blockchain network in the aviation industry to build trust and address the issue of counterfeit aircraft parts within the supply chain. Jensen et al. (2022) discuss and implement a blockchain-based Aircraft Maintenance Record System to ensure record integrity and traceability, utilizing Hyperledger Besu as the platform for their proposed architecture.

Rolinck et al. (2021) explore the use of blockchain as a data management system to conduct a more thorough and effective Life Cycle Assessment (LCA) of aircraft components. They provide an example using the life cycle process for aircraft maintenance, overhaul, and repair (MRO), detailing potential transactions that could be recorded on a blockchain network. Smart contracts were employed to implement LCA logic for gathering and preprocessing input and output flows throughout the project, with the implementation carried out on Hyperledger Fabric. The application of blockchain technology was found to be promising, resulting in a comprehensive LCA.

G.T.S. Ho et al. (2021) propose a blockchain-based system for tracking the traceability and condition of aircraft spare parts from Original Equipment Manufacturers (OEMs) through the supply chain. The architecture was designed using Hyperledger Composer, which supports the Hyperledger Fabric runtime. Their results demonstrated improved visibility of aircraft parts, enhanced security, and better coordination among all supply chain participants.

Ensuring asset traceability and consistent asset status is challenging due to the existence of various record systems among different stakeholders, including manufacturers, distributors, and retailers. Blockchain technology, with its ability to provide secure and private records and facilitate smart contracts in transactions, holds significant potential for aviation activities that involve multiple parties and require reliable record traceability. The implementations

mentioned can substantially improve transaction processes and uphold data security, which is crucial for aviation activities.

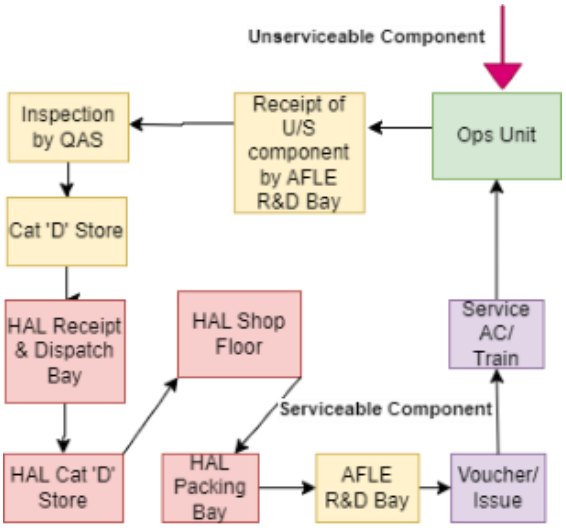
2.3. Blockchain-based system architecture

The aim of this paper is to propose a blockchain-based transaction system to address issues related to provenance tracking, asset monitoring, and information security when an unserviceable (U/S) aircraft component is sent for repair. This section first outlines the flow of U/S aircraft components in the existing scenario, detailing the roles of all involved organizations: the Operational Unit (Ops Unit), the Air Force Liaison Establishment (AFLE), and the HAL Division. Following this, an analysis of the operational processes and organizational relationships will be presented, which informs the design of the proposed blockchain-based system.

2.3.1. Existing Component Workflow & Proposed Operational Process

Figure 1 (refer with: Fig. 1) shows the component workflow in the existing system. The flow starts when a component becomes 'U/S' at the Ops Unit. The Ops Unit creates a Transfer Voucher and dispatches it to AFLE, where it is received by the Receipt & Dispatch Cell (R&D Cell) of AFLE. The R&D Cell, after documenting the receipt of the faulty component, hands it over to the Quality Assurance Section (QAS). The QAS checks the component's status and confirms the defect. The QAS then transfers the component to the Cat 'D' store, where all 'U/S' items are stored. The Cat 'D' store completes the paperwork for Loan In/Loan Out and finally hands the component over to HAL.

Figure 1: Existing Workflow



At HAL, the component is received by the R&D (Receipt and Dispatch) cell, which then transfers it to the HAL Cat 'D' store. The HAL Cat 'D' store performs a thorough inspection of the item to ensure it has been received complete with all necessary cables and associated subcomponents needed to diagnose and repair the fault. Based on this assessment, the store determines the nature of the fault and forwards the component to the relevant Shop Floor for actual repair work. Once the Shop Floor completes the repair, the now serviceable (S) component, along with a Dispatch Advice (DA), is handed over to the Packing Bay. The Packing Bay ensures appropriate packaging and returns the item to AFLE with a Packing Note and invoice. At AFLE, the R&D cell dispatches the serviceable item back to the Ops Unit via suitable means, such as a service aircraft. The Ops Unit receives the serviceable item, along

with any Dispatch Advice regarding operational procedures or precautions. Finally, the Ops Unit installs the component in its aircraft.

Figure 2 (refer with: Fig. 2) illustrates the typical operational process for managing 'U/S' component operations and the collaboration among the organizational parties, including the sub-departments of the Ops Unit, AFLE, and HAL Division. The proposed blockchain-based system, utilizing decentralized distributed ledger technology, aims to enhance information security and transparency regarding 'U/S' components among stakeholders. This operational implementation scenario demonstrates how organizational participants can manage, input data, and monitor activities at each stage.

Key elements of the proposed blockchain network include the asset (i.e., the 'U/S' component), logistics delivery services where data is managed under the blockchain, and encryption mechanisms. Essential data about the asset—such as its current state, location, and custodian—is crucial for daily transactions, reliable interactions, and continuous asset monitoring. For instance, the Ops Unit will input critical details about the asset, such as its serial number and fault description, into the system. The Ops Unit can then monitor the delivery status of the dispatched component and track the repair status from the HAL Division through the blockchain-based system. Permissions for sharing and accessing information are governed by the access control policy defined in the smart contract logic and digital signature protocol to ensure data security and integrity.

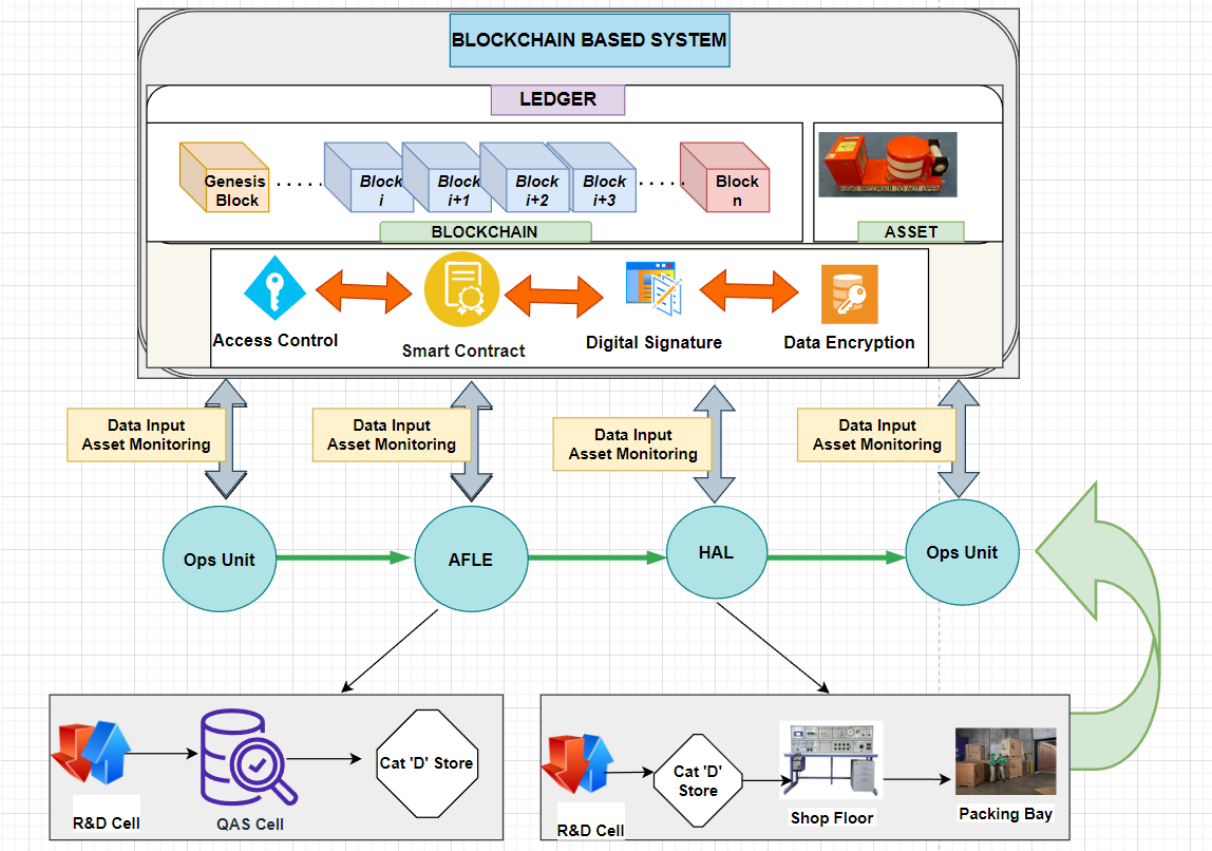
2.3.2. Blockchain-based system architecture

Blockchain technology has enhanced transparency and information security through its decentralized distributed framework. Leveraging the Hyperledger Fabric mechanism and current operations for managing 'U/S' components between the IAF and HAL, a comprehensive architecture for a blockchain-based component system is illustrated in Figure 3 (refer with: Fig. 3). This architecture enables organizations to manage and update activities related to dispatch, repair, maintenance, and the entire component lifecycle.

Participants in this system, referred to as system users, include the Ops Unit, AFLE departments, and HAL Division departments. These users are equipped with a front-end client application to interact with and execute transactions related to aircraft parts within the Hyperledger Fabric network. Transactions are governed by smart contracts, also known as chaincode, which are linked to consensus and validation mechanisms to ensure consistent and accurate execution.

The proposed system's modular architecture is characterized by a flexible design that provides high levels of privacy, resilience, adaptability, and scalability. The versatile and modular nature of Hyperledger Fabric is well-suited to our use case, ensuring both scalability and privacy preservation.

Figure 2: Operational Process with blockchain-based system



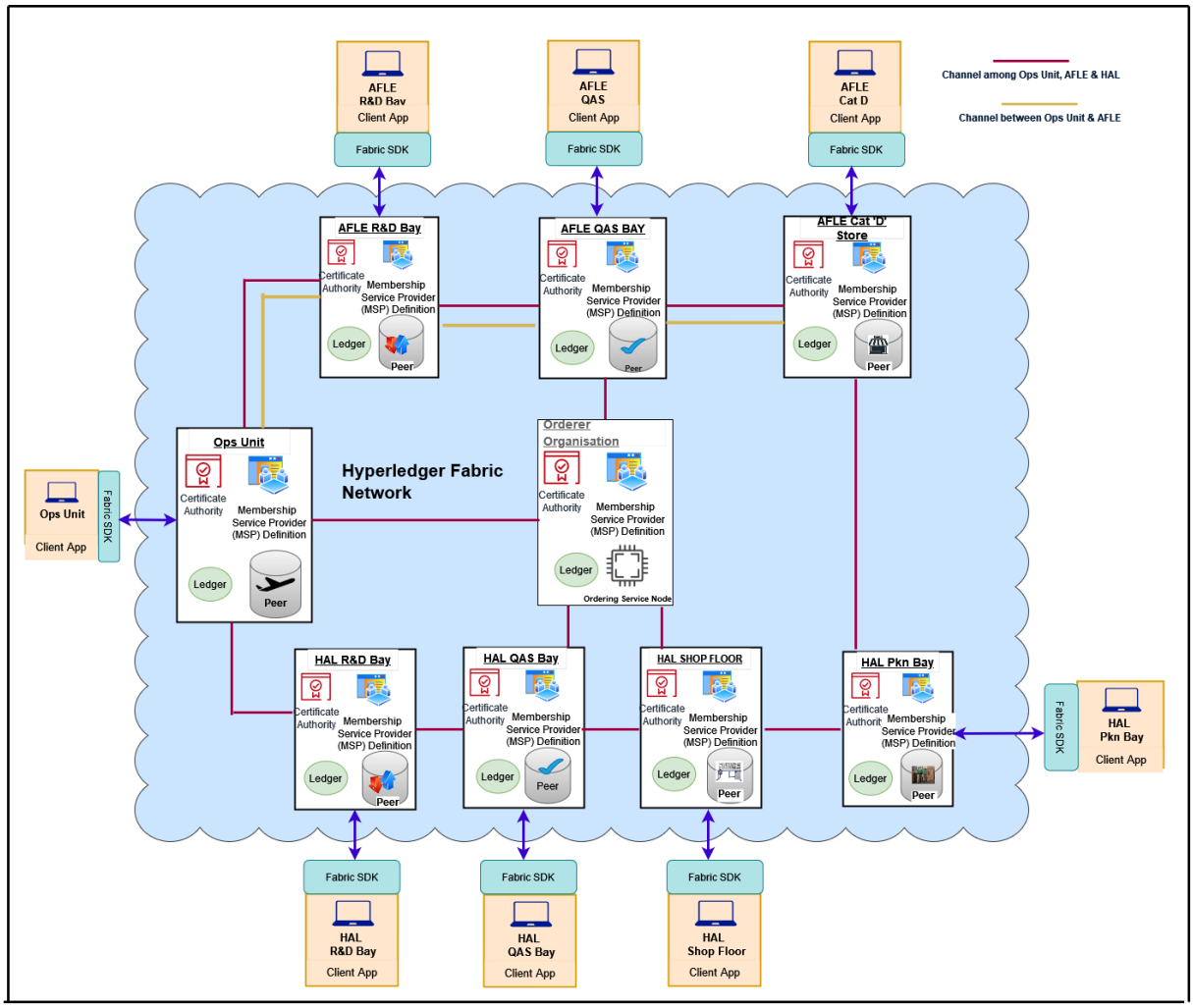
The proposed Hyperledger Fabric network includes one peer node for the Ops Unit, three peer nodes for the AFLE departments, and four peer nodes for the HAL Division departments. Each peer node hosts instances of chaincodes and maintains its own copy of the ledger to ensure secure and immutable recording, tailored to specific business operations. All peers are interconnected through a common channel, enabling them to collaborate by sharing and managing identical copies of the ledger associated with that channel.

As peers host both chaincodes and ledgers, client applications connect to the peer nodes using the Fabric Software Development Kit (SDK) to access resources such as transactions and ledger queries. For example, a client application associated with the Ops Unit peer can initiate a transaction proposal to update the ledger by invoking the chaincode.

The ordering service entity, or ordering node, within the Hyperledger Fabric network employs deterministic consensus algorithms. This node processes transaction orders based on the endorsement of chaincode execution, which enhances the scalability and performance of the Fabric network. The ordering service identifies authorized transactions, aggregates them into blocks, and then dispatches these blocks to the executing peers.

To engage in transactions within a specific channel, each participating organization must possess a Membership Service Provider (MSP) identity. An MSP consists of a set of files incorporated into the network configuration, defining an organization's internal and external characteristics. This setup implies that each organization has an approving body responsible for determining its administrators and granting transaction privileges. Certificate Authorities (CAs) generate credentials representing these identities, while the MSP maintains a file containing authorized identities. Consequently, when an organization wishes to join a channel, its members must be included in the channel configuration by the MSP.

Figure 3: Blockchain-based system architecture for 'U/S' component management between IAF & HAL



Local MSPs are organized as a folder structure within the file system, while channel MSPs are defined within the channel configuration. Channels are established based on the specific information-sharing security requirements of organizational operations. Some organizations may prefer not to disclose confidential information to their competitors. Therefore, private channels can be created within the blockchain network to facilitate secure communication. For example, the Ops Unit and AFLE, both part of the larger IAF organization, can have a separate channel for their communications, distinct from the common channel that includes HAL peers. This separation allows them to exchange confidential information without involving HAL Division peers.

Figure 4 (refer with: Fig. 4) illustrates a channel's transaction workflow, showing interactions between eight client applications and eight peers representing various organizations in the common ledger. Initially, each client application creates a transaction proposal and sends it to all peers for approval. For example, the Ops Unit client application creates transaction T1 and sends proposal P to each of the channel's eight peers. Each peer endorsing the transaction receives the proposal and executes the corresponding chaincode to generate a response. The peer then uses its private key to create a digital signature, certifying the proposal response.

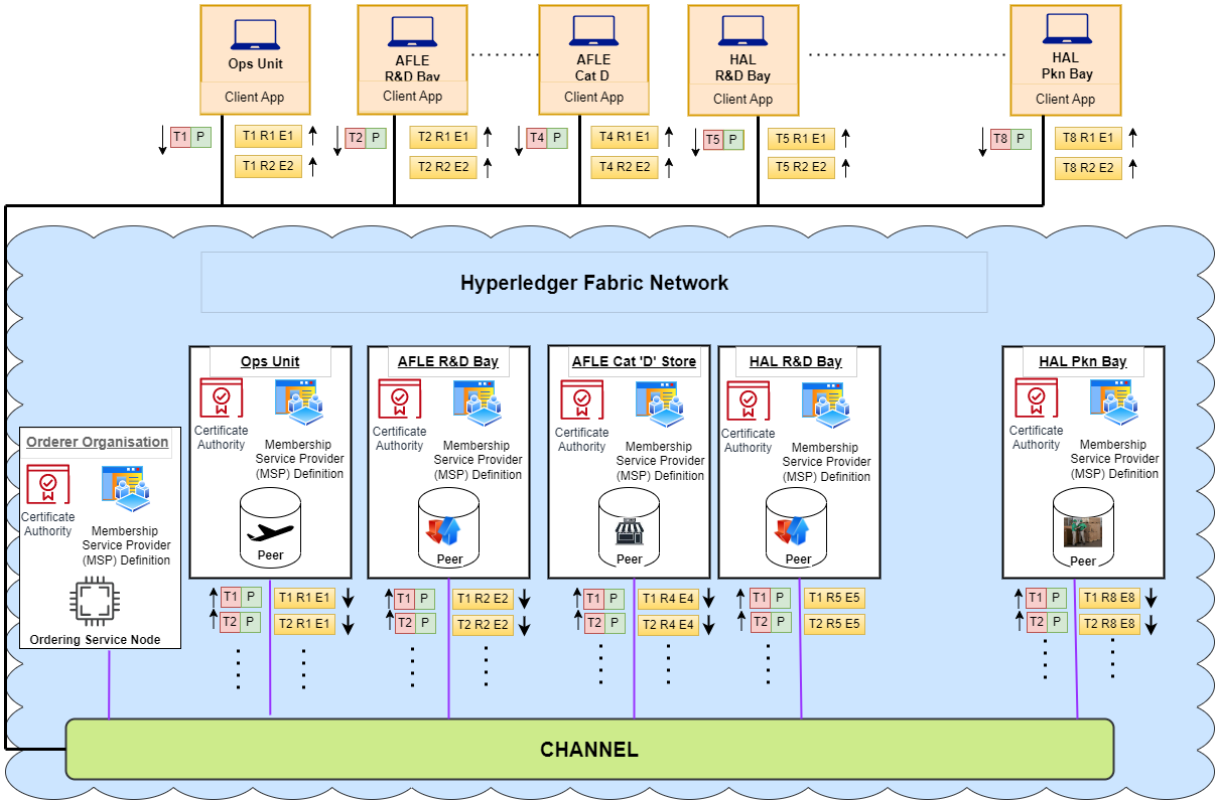
For instance, when HAL R&D Bay uses transaction T1 proposal P to execute its chaincode, it produces response R1 with endorsement E1. Each related peer follows the same process. The first stage of the transaction flow concludes when the client applications have received

sufficient feedback from the peer set, indicating that consensus has been reached as all channel organizations have approved the proposed change to the ledger.

Subsequently, the client applications send their finalized transaction proposals to the ordering service node, as shown in Figure 5 (refer with: Fig. 5). For instance, the Ops Unit client application sends transaction T1 and the endorsed responses (E1, E2, ..., En) to the ordering service node.

The AFLE R&D Bay similarly sends transaction T2 to the ordering service node, along with responses and endorsements from peers E1, E2, ..., En. All client applications across organizations follow this process. The ordering service node then organizes the submitted transactions—such as T1, T2, T3, T4, T5, T6, T7, and T8—along with relevant channel data like the desired block size and elapsed maximum duration, in strict sequential order. Figure 5 illustrates how these transactions are encrypted into a single transaction hash value. The new block, containing these transactions, is then prepared for addition to each organization's ledger within the channel. The block's hash value is generated by combining the hash value and timestamp of the previous block with the new data. Once created, all validated transactions within the block become immutable, preventing ledger forks and conflicting versions.

Figure 4: Transaction Proposal

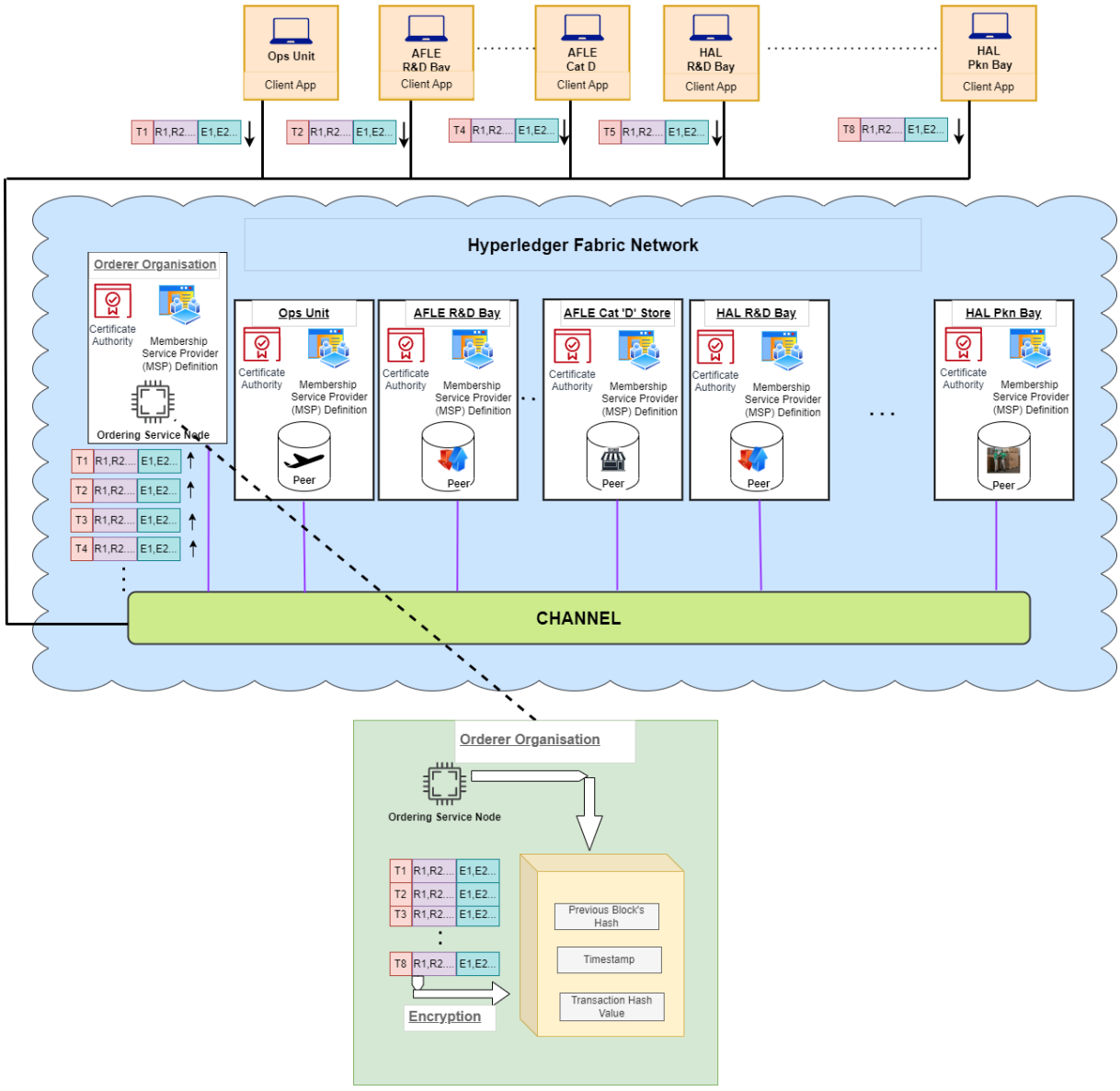


The block is now ready to be distributed and committed to the ledger by the ordering service node. In Figure 6 (refer with: Fig. 6), the ordering service node distributes the new block to every peer, including those in the Ops Unit, the AFLE departments (AFLE R&D Bay, AFLE QAS Bay, and AFLE Cat 'D' store), and the HAL departments (HAL R&D Bay, HAL Cat 'D' store, HAL Shop Floor, and HAL Packing Bay).

To ensure compatibility, the peers perform a ledger consistency check. Each peer independently validates the block and adds it to its respective ledger. Updates are regularly shared with other peers according to the endorsement policy specified by the chaincode. To

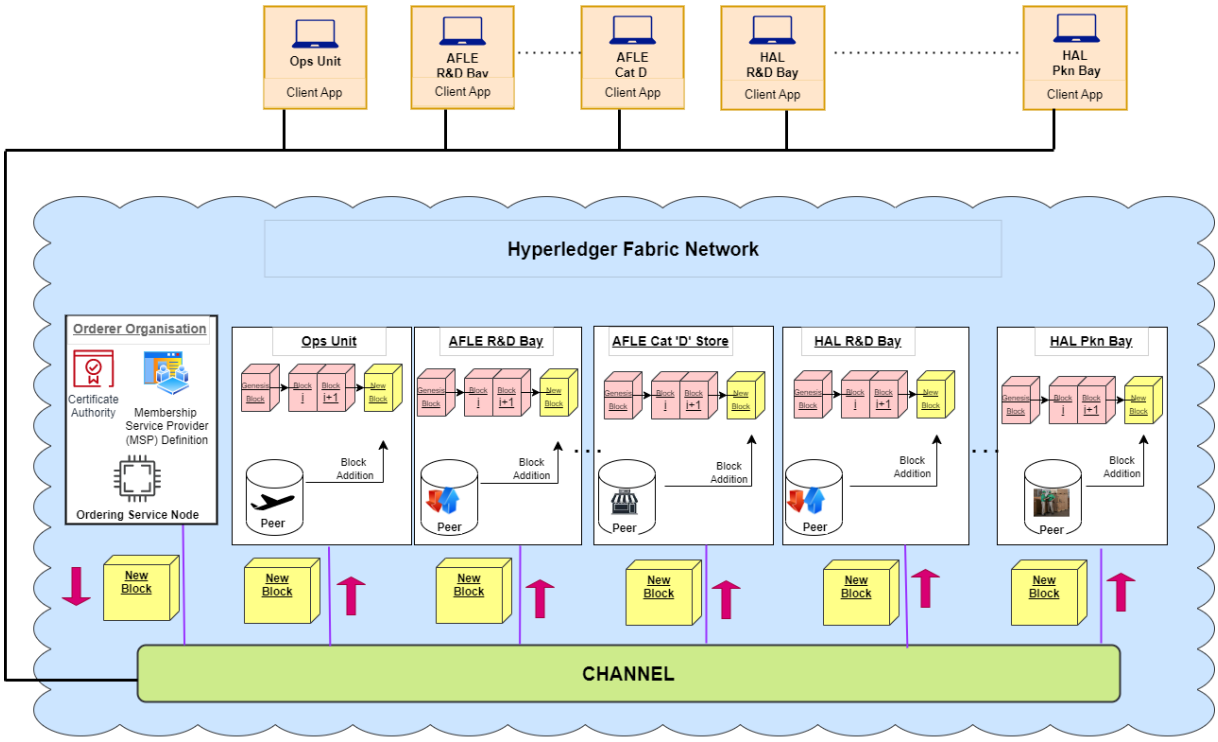
maintain uniform results and outcomes, a peer may reject the addition of the block if it does not comply with the endorsement policy.

Figure 5: Ordering & PackingTransactions into a block



Once the transaction is processed and the blockchain operation is complete, the client application receives a block event notification containing a summary of the block validation information. At this point, the overall blockchain operation is considered complete.

Figure 6: Validation & Commit



3. Results

3.1. Implementation with Hyperledger Fabric

The tools and hardware details used to implement the proposed blockchain-based system are provided in Table 1 (refer with: Tab. 1). All applications were executed using a Lenovo Ideapad Z580 with a 2.40 GHz Intel Core i3-3110M processor and 4 GB of memory. Docker Compose (version 2.16.0) and Docker Engine (version 23.0.1) served as the back-end environment and container configuration for the system. The test network provided by Hyperledger Fabric initially includes two participant organizations and one orderer organization, each with a single peer by default. To accommodate our use case, which required an additional participating organization and more peers, *registerpeer.sh* script files and *peer x org y.yaml* network files were created. The assets and transactions were visualized and implemented using chaincode written in the general-purpose programming language Golang (version go1.20.4) and integrated with the business network definition containing the necessary participants.

The smart contract file, known as chaincode in Hyperledger Fabric, contains the execution procedures for asset and participant interactions and transactions. The asset life cycle, implemented in the smart contract, is depicted in Figure 7 (refer with: Fig. 7). The Golang smart contract file implements this life cycle through methods such as creating, transferring, deleting, and reading assets from the ledger. Access control is enforced in the smart contract code to ensure that these methods can only be invoked by authorized entities based on the current state of the asset.

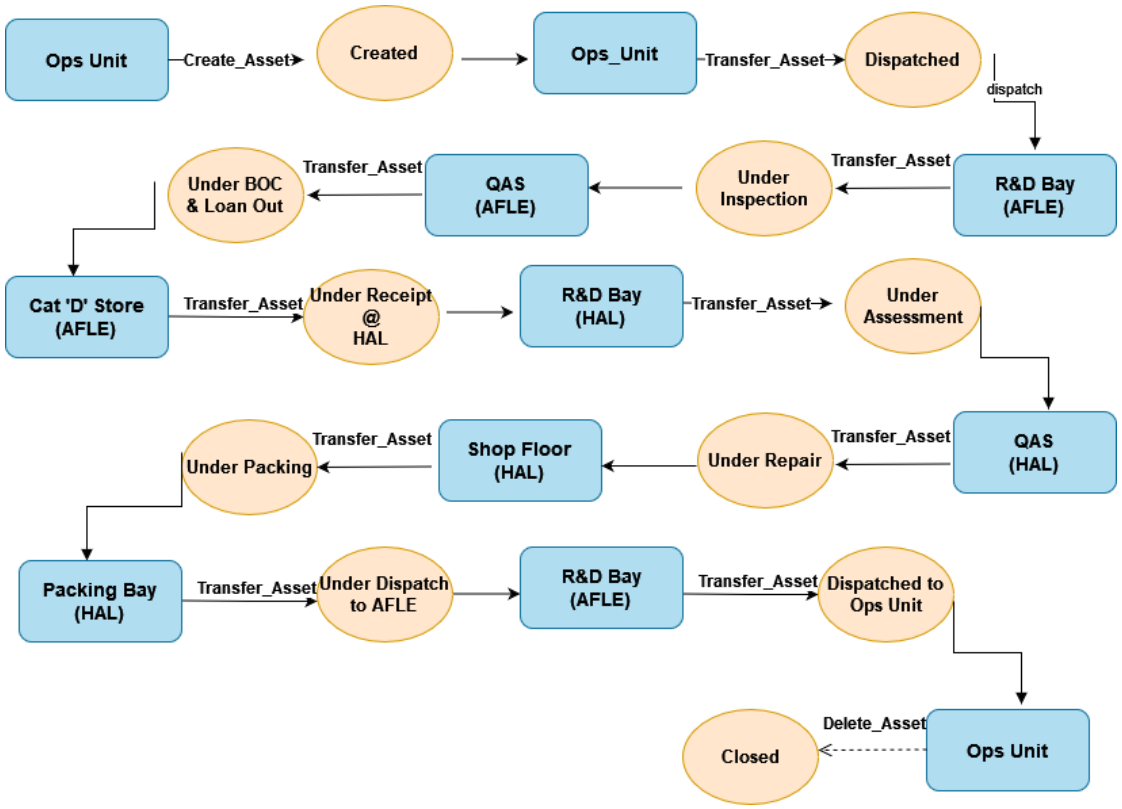
Table 1: Tools for Proposed System Implementation

System Component	**Description**
Git (For Version Control)	2.25.1
Hyperledger Fabric	2.4.7
Certificate Authority (CA)	1.5.5
Docker-Compose	2.16.0
Docker-Engine	23.0.1, build a5ee5b1
Curl HTTP Client	7.68.0 (x86_64-pc-linux-gnu)
Golang	gol.20.4 Linux/amd64
Operating System	Linux Ubuntu 20.04.6 LTS
OS Type	64-Bit
Disk Capacity	500 GB

The primary objective of the blockchain network is to store information in a distributed manner, where each block contains an encrypted transaction and hash functions to ensure information security. The service-oriented system architecture integrates smart contract features, security, and integrity management within the distributed ledger framework, as illustrated in the figures. End-users of the system (e.g., Ops Unit, AFLE, and HAL Division) can perform specified transactions by invoking methods provided in the smart contract. Successful execution of the smart contract and consensus algorithms will result in ledger updates and synchronization across all peers. For instance, the Ops Unit will use the *Create_Asset()* method to create a new asset in the ledger, uniquely identified by its serial number. This serial number is crucial for any subsequent updates by peers using the transactional function *Transfer_Asset()*.

This decentralized blockchain network, leveraging the Hyperledger Fabric platform, aims to enhance the efficiency and quality of 'U/S' aircraft component management between IAF and HAL. Currently, aircraft component management involves extensive paperwork and communication between IAF and HAL, leading to high processing times and cost inefficiencies. Implementing the entire process on the blockchain network can streamline these management procedures.

Figure 7: Asset Life Cycle Implemented in Smart Contract



4. Discussion

The implemented system is capable of merging events from different sources with access authorisations and mapping rules of the business process. Through the proposed blockchain-based system, all the stakeholders in the aircraft component journey from ‘U/S’ at the Ops Unit to ‘S’ back at the Ops Unit can perform transactions and communicate securely. The proposed Hyperledger Fabric network has aimed to connect each organisation and heighten efficiency during aircraft component transactions. All related organisations can share and receive the data through the system thereby reducing costs, communication time, and documentation work.

The significant benefit of tracking enables the Ops Unit to accurately locate the dispatched component and its current status with lesser chances of incorrect information obtained telephonically earlier. It will also benefit the HAL Shop Floor Department to plan their manpower availability and provision the spare parts, test rigs, etc required to cater for repair of the 'U/S' component when it reaches there as they will come to know about the component well in advance as soon as it has been dispatched physically and transaction for the same has been invoked by the Ops Unit. All in all, this will ultimately result in lesser AOG time for an aircraft due to want of an unserviceable component which has gone for repair thus improving the availability of an aircraft for flying operations. Thus, it will ensure better operational readiness of the fleet for actual operations. Apart from this the information transparency and visibility enable better planning in component rectification with reduced parts tracing time, and faster response improves the efficiency in the maintenance work. Since the confidentiality of component information is crucial for operational readiness, the security of the data is an essential element in designing the Hyperledger Fabric network. Organisational peers can communicate freely within the channel and peers without the channel’s certification are not allowed to enter and read the information inside it. All the transaction records are saved in the

ledger, where every participant within the channel owns a copy. For every transactional operation, the ledger will be updated with data encryption and access control.

A comparative analysis of various parameters between the existing system and the proposed Blockchain-based system is given in Table 2 (refer with: Tab. 2) for quick reference to the benefits of this system.

Table 2: Comparative Analysis of Existing System & Blockchain-Based System

Comparative Analysis		
Parameter	**Existing System**	**Blockchain-Based**
Transaction	Manual	On Blockchain Network
Liasioning	In Person/Telephonically	Less Liasioning Requirements
Record Keeping	All Orgs Maintain Own Records	Shared Distributed Ledger
Record Mismatch	High Probability	Zero Probability
Trust	Partial	Trustless Environment
Coordination	Poor	Excellent
Spare/Manpower Provisioning	Difficult	Easy
Pinpoint Identification	Difficult	Easy
AOG Downtime	High	Low
Accountability of Workmanship	Difficult	Timestamped Accountability

5. Conclusion

In this research paper, we proposed a blockchain-based system for tracking and monitoring the status of unserviceable aircraft components, from the Ops Unit through the entire chain of stakeholders. Utilizing Hyperledger Fabric, we designed a comprehensive data model and system architecture that integrates the entire aircraft component movement scenario, facilitating secure and efficient information sharing through consensus and channel mechanisms. A comparative analysis between the existing and proposed systems indicates that our blockchain-based solution significantly enhances information visibility, traceability, and inter-organizational communication across the aircraft component movement chain.

Despite the demonstrated improvements in efficiency and security, several limitations and areas for potential enhancement remain:

1. **User Interface**: Currently, peer interactions are managed via command-based method invocations. Developing a front-end application using the Fabric Software Development Kit (SDK) could streamline user interactions within the network.
2. **Data Analytics**: The proposed system focuses primarily on information recording. Integrating data analytics could offer valuable insights, such as identifying recurring faults in components and understanding repair trends. Statistical analysis could also help track components with frequent issues, providing data for better future provisioning.

3. **Broader Applications**: Building on the findings of this research, the blockchain-based system could be explored for other domains within IAF, particularly in logistics and supply chain management.

Overall, the proposed blockchain system promises substantial benefits for aircraft component management, ensuring improved operational readiness and efficiency. Future research and development can further enhance its capabilities and explore its applicability across various domains.

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