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Supply Chain Management

Postgraduate Dissertation

Enhancing Aircraft Parts Traceability in the Aviation Supply Chain through Blockchain Technology: A Grounded Theory Approach.

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Abstract

In order to address significant issues with aircraft parts traceability within the aviation supply chain, this thesis investigates the incorporation of blockchain technology. Inconsistent documentation, the possibility of fake parts, manual process inefficiencies, and the difficulties of complying with international regulations are some of these difficulties. The study uses a grounded theory methodology to identify the main challenges and opportunities related to blockchain deployment by analyzing qualitative data gathered from expert interviews. The report emphasizes how blockchain may be used to provide immutable record-keeping, real-time data sharing, increased transparency, and the development of trust among manufacturers, suppliers, and maintenance companies, among other stakeholders. Significant adoption challenges are also identified by the study, such as high implementation costs, restricted compatibility with older corporate systems, regulatory mismatch, and cultural reluctance. Because blockchain can establish a single source of truth, lower the danger of counterfeiting, and facilitate predictive maintenance, it has the potential to revolutionize aviation supply chains. As requirements for successful implementation, the report highlights the significance of industry cooperation, regulatory harmonization, and pilot projects. Furthermore, blockchain's usefulness in predictive maintenance and aviation part lifecycle management may be further increased by combining it with cutting-edge technologies like IoT and AI. The results highlight the need for customized, scalable solutions that accommodate to industry-specific needs, even as they show how revolutionary blockchain technology may be. The thesis ends with helpful suggestions for aviation stakeholders, such as giving pilot projects top priority, encouraging regulatory alignment, and supporting training programs to close the knowledge gap. Future studies will examine how blockchain may be integrated with cutting-edge technologies, provide affordable frameworks for small and medium-sized businesses, and examine the wider effects of blockchain on aviation sustainability and compliance.

Keywords

Aircraft parts traceability, aviation supply chain, blockchain technology, grounded theory, counterfeit, IoT integration, aviation industry digitalization, regulatory compliance

Περίληψη

Για την αντιμετώπιση σημαντικών ζητημάτων που σχετίζονται με την ιχνηλασιμότητα ανταλλακτικών αεροσκαφών στην εφοδιαστική αλυσίδα του αεροπορικού κλάδου, αυτή η διατριβή διερευνά την ενσωμάτωση της τεχνολογίας blockchain. Αυτά τα ζητήματα περιλαμβάνουν την ασυνεπή τεκμηρίωση, την πιθανότητα ύπαρξης πλαστών ανταλλακτικών, τις αναποτελεσματικότητες των μη αυτοματοποιημένων διαδικασιών και τις δυσκολίες συμμόρφωσης με τους διεθνείς κανονισμούς. Η μελέτη χρησιμοποιεί τη μεθοδολογία grounded theory για να εντοπίσει τις κύριες προκλήσεις και ευκαιρίες που σχετίζονται με την εφαρμογή της τεχνολογίας blockchain μέσω της ανάλυσης ποιοτικών δεδομένων που συλλέχθηκαν από συνεντεύξεις με ειδικούς στο χώρο. Η μελέτη αναδεικνύει πώς το blockchain μπορεί να χρησιμοποιηθεί για την παροχή αμετάβλητης καταγραφής δεδομένων, τη διαμοίραση δεδομένων σε πραγματικό χρόνο, την αυξημένη διαφάνεια και την ανάπτυξη εμπιστοσύνης μεταξύ των κατασκευαστών αεροσκαφών, προμηθευτών και εταιρειών συντήρησης, καθώς και άλλων ενδιαφερόμενων μερών. Εντοπίζονται επίσης σημαντικές προκλήσεις υιοθέτησης, όπως το υψηλό κόστος υλοποίησης, η περιορισμένη συμβατότητα με παλαιότερα εταιρικά συστήματα, η αναντιστοιχία κανονισμών και η πολιτισμική απροθυμία. Επειδή το blockchain μπορεί να καθιερώσει μια μοναδική πηγή αλήθειας, να μειώσει τον κίνδυνο πλαστογραφίας και να διευκολύνει τη συντήρηση πρόβλεψης, έχει τη δυνατότητα να φέρει επανάσταση στις εφοδιαστικές αλυσίδες του αεροπορικού τομέα. Η μελέτη υπογραμμίζει τη σημασία της συνεργασίας της βιομηχανίας, της εναρμόνισης των κανονισμών και των πιλοτικών έργων ως βασικές προϋποθέσεις για επιτυχή εφαρμογή. Επιπλέον, η χρησιμότητα του blockchain στη προληπτική συντήρηση και τη διαχείριση του κύκλου ζωής των ανταλλακτικών αεροσκαφών μπορεί να αυξηθεί περαιτέρω με τη συνδυασμένη χρήση προηγμένων τεχνολογιών όπως το IoT και η Τεχνητή Νοημοσύνη (AI). Τα αποτελέσματα υπογραμμίζουν την ανάγκη για εξατομικευμένες, κλιμακούμενες λύσεις που ανταποκρίνονται στις ειδικές ανάγκες της βιομηχανίας, ενώ παράλληλα δείχνουν πόσο επαναστατική μπορεί να είναι η τεχνολογία blockchain. Η διατριβή καταλήγει με χρήσιμες προτάσεις για τους ενδιαφερόμενους στον τομέα της αεροπορίας, όπως η προτεραιότητα στα πιλοτικά έργα, η ενίσχυση της εναρμόνισης των κανονισμών και η υποστήριξη εκπαιδευτικών προγραμμάτων για τη γεφύρωση του χάσματος γνώσεων. Μελλοντικές μελέτες θα εξετάσουν την ενσωμάτωση του blockchain με προηγμένες τεχνολογίες, την παροχή οικονομικά αποδοτικών πλαισίων για μικρές και μεσαίες επιχειρήσεις, καθώς και τις ευρύτερες επιπτώσεις του blockchain στη βιωσιμότητα και τη συμμόρφωση στον τομέα της αεροπορίας.

Λέξεις Κλειδιά

Ιχνηλασιμότητα ανταλλακτικών αεροσκαφών, εφοδιαστική αλυσίδα αεροπορίας, μεθοδολογία grounded theory, πλαστογραφία, ενσωμάτωση IoT, ψηφιοποίηση αεροπορικής βιομηχανίας, συμμόρφωση κανονισμών

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CHAPTER 1- Introduction

1.1. Problem Definition Current Status

Currently organizations that operate in various roles such as sellers, distributors, suppliers across aviation industry play a significant role in ensuring the safe operation and airworthiness of aircraft. Civil aviation authorities do not regulate organizations involved in parts supply. Although, it is expected these organizations to operate in accordance with aviation quality and safety standards meeting the minimum criteria, (Vahap, n.d.). It is highlighted that there is no common standard recognized and utilized all over the world and there is a plethora of standards which are accepted according to the regions where aviation activities are taking place. To provide an example, acceptable standard practices for aircrafts registered and maintained under US aviation authority (FAA), shall comply with the established criteria to be considered airworthy. Organizations involved in the SC shall comply with the applicable regulations and authority's instructions including advisory circulars, regulation 14 CFR, part 21 etc. In addition, as part of Maintenance Organizations/Operators standard operating procedures provisions shall be made to standardize supplier evaluation, subcontract control and aircraft parts receiving inspections. The whole process is time consuming requires the involvement of multiple departments (operations, quality assurance, supply chain) and is prone to errors due to the human nature and vast number of components, suppliers. Recently FAA issued a notification (*UNAPPROVED PARTS NOTIFICATION*, n.d.) over fake CFM engine parts, regarding GE bushing P/N: 1856M94P01, sold by AOG Technics LTD, located in London without FAA production approval. AOG Technics LTD is not an FAA production approval holder and form FAA 8130-3 were falsified. FAAs recommendation to the operators of these engines to perform a one-time inspection in their engines and inventories to verify that those parts are not installed or kept as spare. Quarantine of these parts was suggested until further notice. Additional information is provided as part of literature review and an example of an organization's supplier evaluation is examined in detail.

1.2. Purpose of the dissertation

Enhancing Aircraft Parts Traceability in the Aviation Supply Chain through Blockchain Technology: A Grounded Theory Approach. This thesis investigates the challenges of aircraft parts traceability in the aviation SC and explores the potential benefits of blockchain technology's implementation. Grounded in empirical data collected from subject matter experts (SMEs), grounded theory methodology is being used to develop a substantive theoretical framework. The research contributes to the understanding of how blockchain can address existing issues and improve safety, compliance and efficiency in aircraft maintenance and SCM. Regarding the dissertation's classification qualitative research is performed by utilizing interviews and semi-structured questionnaires prompting extensive answers and an initial theoretical framework is studied.

1.3. General Methodology-Approach Followed

This thesis employes a qualitative research approach based on grounded theory to explore aircraft parts traceability in the aviation supply chain through blockchain technology. The study begins by illustrating the complexity of current supplier evaluation and parts receiving inspection procedures within aviation organizations, emphasizing the involvement of multiple stakeholders and potential for human errors. To provide a background, the thesis includes a comprehensive review of digitalization trends in the supply chain, focusing on Industry 4.0, Industry 5.0 and Aviation 4.0. A dedicated section on blockchain technology describes the blockchain structure and possible architectures suitable for aviation parts traceability and highlights its applications in the aviation industry as those are derived by literature. The research methodology centers on grounded theory, supported by data collection through structured questionnaires and interviews. These questionnaires were designed around three key research questions aimed at producing detailed responses for in-depth analysis, through application of grounded theory. ChatGPT was used as an analytical tool to implement grounded theory, assisting in coding, categorization and thematic development based on the data extrapolated. The results were interpreted and compared with the research questions and relevant literature, ensuring a comprehensive analysis. Finally, the thesis discusses implications for industry practice, proposes future research directions and concludes with findings that highlight the transformative potential of blockchain technology for enhancing A/C parts traceability in the aviation supply chain.

1.4. Thesis Findings

The findings of this thesis demonstrate the revolutionary potential of blockchain technology to improve aviation supply chain traceability. This study used grounded theory to identify basic problems including inconsistent paperwork, manual processes, and cross-border regulatory complexity. Blockchain can help with these problems by providing real-time data sharing, immutable record-keeping, and increased transparency. According to the study, blockchain's capacity to create a single source of truth reduces the risk of counterfeiting while simultaneously promoting cooperation and confidence amongst stakeholders, including suppliers, manufacturers, and maintenance companies. To fully achieve blockchain's promise in revolutionizing aviation supply chain management, however, customized solutions, pilot projects, and cooperative frameworks are required due to obstacles like integration with old ERP systems, high installation costs, and regulatory mismatch.

1.5. Limitations of the Thesis

While this thesis provides valuable insights into the potential of blockchain technology for enhancing A/C parts traceability in the aviation supply chain, certain limitations should be acknowledged. A significant constraint was the limited prior experience of interviewees with blockchain applications in the aviation industry. Although most stakeholders expressed a positive outlook on the technology’s potential, their perspectives were theoretical and lacked practical exposure to implementation challenges and complexities. Additionally, the number of interviewed stakeholders was limited which falls short of the recommended minimum of 15 applicants typically suggested for grounded theory research. This limitation may affect the generalizability of the findings. Furthermore, no iterative interviews were conducted, as the primary objective was to explore the application of grounded theory rather than achieving theoretical saturation. Future research could address these limitations by involving a broader range of industry experts with hands-on blockchain experience and conducting multiple interview-rounds to refine emerging themes and theoretical constructs.

1.6. Structure of the Thesis

As part of this subchapter an introduction of all the subsequent main chapters is performed aiming to introduce to the reader the context of the thesis and clarify the scope of each section of this document. Chapter 1which is the introduction chapter is excluded.

Chapter 2: Background and Contextual Analysis of Aircraft Spare Parts Management

This chapter provides a comprehensive overview of the challenges and dynamics in managing spare parts, setting the stage for exploring innovative solutions. Introduces the complexity of supplier evaluation and parts receiving inspection processes in Maintenance, Repair and Overhaul organizations. It highlights the involvement of various stakeholders and potential human errors, setting the stage for exploring blockchain-based solutions. Discusses the technological evolution of supply chains, emphasizing the shift toward digital ecosystems. It focuses on enabling technologies such as the Internet of Things (IoT), artificial intelligence (AI), data analytics etc., highlighting their impact on multiple sectors including aviation. Introduction of blockchain technology is performed, explaining its core principles, functionalities and advantages. It highlights blockchain's applications in aviation, particularly in parts traceability, maintenance records, and regulatory compliance.

Chapter 3: Literature Review-Blockchain Technology for the Management of Aircraft Spare Parts

This chapter provides a detailed review of existing literature and integrates insights on blockchain's role in managing aircraft spare parts.

Chapter 4: Methodology and Application

This chapter outlines the foundation for using grounded theory as the research methodology, emphasizing its suitability for exploring emerging concepts in aviation supply chain management. Details regarding the data collection process, focusing on questionnaires designed around three core research questions to capture expert insights on blockchain's potential for enhanced traceability. Integration of ChatGPT is explained particularly on how it was used to implement grounded theory by coding, categorizing and interpreting the data, enabling a structured analysis of themes and concepts.

Chapter 5: Analysis

This chapter presents the results derived from applying grounded theory, including identified themes, patterns and theoretical constructs relevant to blockchain-based traceability in aviation.

Chapter 6: Discussion

This chapter compares the study's findings with existing literature, highlighting similarities, differences and new insights. It discusses the practical implications of the research and how blockchain can address traceability challenges in aviation.

Chapter 7: Conclusions

The thesis concludes by summarizing key findings. It also suggests recommendations for industry stakeholders and identifies future research directions to advance blockchain integration in the aviation supply chain.

CHAPTER 2- Background and Contextual Analysis of Aircraft Spare Parts Management

2.1. Background and Rationale-Example of an MRO's Suppliers Evaluation and Parts Receiving Inspection Criteria

Understanding the complexity of procurement options for aviation spare parts requires consideration of a number of factors, including operational needs, budgetary constraints, approved supplier lists, if applicable, receiving inspection protocols, end-user time pressure, documentation requirements, and customs and regulatory arrangements. As per (Kharlov et al., n.d.) the most usual procurement strategies are the following:

- Purchase Option: Which entails direct acquisition of the component, transferring ownership to the buyer. The buyer has full control of the component there are no recurring charges, although the upfront costs are high, including storage and maintenance responsibility. It is highlighted that there is a possibility the component to become obsolete.
- Exchange Option: A serviceable component is supplied immediately, and the defective part is returned for repair. The operator pays for the repair and the exchange fee. The cost is still high due to repair charges and exchange fees although the aircraft downtime is minimized given that the part is swiftly available for replacement. This method is used in cases that an Aircraft is on ground due to a malfunction and a component is needed as soon as possible.
- Advance Repair Option: The airline repairs removed components in advance maintaining replacement units in stock. The risk of an AOG situation is minimized and as a drawback significant inventory investment is required and warehousing costs are increased.

To elaborate in supply chain complexity related with aviation parts procurement a plethora of stakeholders is involved including aircraft manufacturers (OEMs) which are producing aircrafts, major components and subsystems (e.g. Airbus, Dassault, Boeing), approved suppliers and distributors, Maintenance Repair and Overhaul (MRO) providers, logistics and freight forwarders, dangerous goods suppliers, brokers and traders, aftermarket service providers, customs and export control, standards organizations establishing guidelines (ISO, AS/EN9100, OSHA), Civil Aviation Authorities (CAAs) ensuring compliance with aviation standards, quality assurance/third-party auditors certifying suppliers and processes according to industry standards. Organizations monitored by aviation authorities must document and implement all the regulatory requirements applicable to their context. There are organizations that comply with multiple standards and many authorities' regulations (e.g. FAA, EASA, GCAA, etc.). An example of an EASA organization is presented below that aims to comply with Regulation (EU) No 1321/2014 Part 145. Prior the official acceptance of an such an organization from the respective aviation authority an audit is performed to verify compliance with the standards. The first step the organization has to follow is the creation of the Maintenance Organization Exposition (MOE). As part of the MOE Supplier Evaluation and subcontracting and acceptance inspection of aircraft components and materials installation from contractors are required to be documented IAW 145.A.42(b), 145.A.75(b), 145.A.205(a)1,(a)2,(b). A template as an acceptable mean of compliance is presented below:

Type of Providers

When performing maintenance under the established scope of approval, may utilize any parts components, material, maintenance services external to the maintenance organization, by any source or provider falling into the generic categories of the table below:

Table 1 Providers-Sourses-Types of Services

Type of Provider	Definition	Sources	Type of Services
Supplier	Any source providing components, standard parts or materials to be used for maintenance.	•Aircraft/Engine TC Holder. •OEM or PMA of components. •Distributors approved by the OEM. •Part-145 AMO •Part 21 DOA/POA •Brokers	• Components • Consumables • Expendables • Standard Parts • Raw Materials
Contracted organizations	An EASA Part-145 maintenance organization that carries out maintenance under its own approval for another approved maintenance organization	•Part-145 AMO Class B/C rating •Part-145 AMO Class A rating for base maintenance	• Rotable components • Repairable components • NDT services • Base Maintenance
Subcontracted organizations	An organization, not suitably approved to Part-145 that performs aircraft line maintenance or minor engine maintenance or maintenance of other aircraft parts or a specific service as a subcontractor for an organization appropriately approved under Part 145		• Specialized Services
Operators	Any kind of the above-mentioned services and/or parts, may be provided directly by the operator ad-hoc or pooled, under the provisions of an established contract.		

Suppliers Evaluation

In general, a list of approved suppliers, under the ultimate responsibility of the Compliance Monitoring Manager, has to be utilized to monitor the approved suppliers. Depending on the organization's size this may alter. The list of suppliers is not considered part of the MOE and may be revised when required without authority's prior approval. The following information has to be included as a minimum in the supplier list:

- Supplier identification data (name, country, type of business),
- Certification approvals,
- Validity of authorization,
- Last evaluation date

Evaluation Process

Initial or recurrent evaluation of proposed suppliers is performed based on qualifications in terms of quality system, technical capabilities, approvals, delivery, prices, production capacity and service, information pertaining to historical performance including inspection/repair defects reports, customer complaints etc., priority of the intended purchase considering any AOG situations. The evaluation of a potential supplier, has to be proposed to the Compliance Monitoring Manager either from the purchasing department and shall be performed under the following key processes, as applicable:

- Evaluation of the holding approval certifications as applicable (Part-21, Part-145, TC Holder, etc.)
- Quality system assessment according to the requirements established to GM3 145.A.42(b)(i)
- Postal audit or on-site audit.

In case a potential supplier has been deemed eligible for acceptance by the organization the supplier list has to be amended and therefore can be used by purchasing department to place orders on the relevant supplier. Supplier information record is created including approval certificates, audit reports, quality system assessments, purchase history, incoming inspection reports, defect reports. Monitoring of the approved suppliers is performed in scheduled intervals for performance and positive feedback. Monitoring of contractors and subcontractors shall be also documented and implemented as part of the MOE, although no further information is provided as part of this thesis, the principles used are the similar with suppliers' evaluation.

Acceptance/Inspection of Aircraft Components and Materials Installation

All components utilized for maintenance from outside sources are classified in five (5) categories components in satisfactory condition, unserviceable components, unsalvageable components, standard parts, material (consumable or raw). Below a brief description for each of those categories is presented:

- Components in satisfactory condition: Are those components, in serviceable condition, released on an EASA Form 1 or equal and marked accordingly.
- Unserviceable components: Are those components that should undergo maintenance, according to the provisions of EU regulation No. 1321/20214 due to expiry of the service life limit, non-compliance with an AD, inability to determine airworthiness status, inability to determine eligibility for installation, evidence of defects or malfunctions or being installed on an airplane that was involved in an accident or incident.
- Unsalvageable components: Are considered those components that have non-repairable defects whether visible or not, do not meet design specifications and cannot be brought into conformity, are subjected to unacceptable modification or rework that is irreversible, have reached or exceeded their mandatory life limitations or having missing or incomplete related records, their airworthy condition cannot be reinstated due to exposure to extreme forces, heat or adverse environmental conditions, conformity with an applicable AD cannot be accomplished, maintenance records and/or traceability to the manufacturer cannot be retrieved.
- Standard parts: Manufactured in complete compliance with a published specification (e.g, NAS, AN, SAE, ANSI, EN, etc.), so that anyone may manufacture the part. An

EASA Form 1 or equivalent is not normally issued, and, therefore, none should be expected. The compliance shall be specified in the maintenance data and the parts must be escorted by evidence of conformity traceable to the appropriate standard.

- Material: Divided into consumable and raw. Consumables are the material which are used only once (e.g. lubricants, paints, sealants etc.). Raw material that requires further work to make it into a component part of the aircraft (e.g. metal, plastic, wood etc.). Should meet the required specification and have appropriate traceability. Also, raw materials shall be accompanied by documentation clearly relating to the particular material and containing a conformity to specification statement as well as the manufacturing and supplier source.

Component/Material Certification

For standard parts not accompanied by an EASA Form 1, the documentation that accompanies such parts should clearly relate to the particular parts the Batch/LOT Number to address manufacturer's possible recalls, given that a S/N is not provided in most cases. Contain a conformity statement plus both the manufacturing and supplier source. A Certificate of Conformity (CofC) signed by the manufacturer should be provided to establish the traceability to the manufacturer and additionally it should refer to the applicable standard/specification. Caution should be exercised when receiving a certificate that does not establish traceability to the manufacturer. The ATA 106 Form is sometimes provided which is a commercial form recommended by ATA (Air Transport Association) and it is not binding, the form is used to facilitate commerce and it is not supported by the aviation regulations and most importantly can be signed by companies that do not hold EASA or FAA approval certificate. This information can be useful to the analysis performed by an engineer at the time of installation as it provides commercial traceability that helps the end user know who to contact in the event of problems with the part. When an ATA 106 form is provided it shall be accompanied by the respective CoC, signed by the manufacturer. These documents have to be linked somehow e.g. by a P.O. number or batch/LOT number. Items (fasteners, washers, nuts, etc.) obtained in batches should be provided in a package. The packaging should state the applicable specification/standard, part number, batch number, quantity of items and the manufacturing sources. If the material is acquired from different batches, receipt documentation for each batch should be provided. It is emphasized that an engineer prior to initiation of any maintenance action, requests a work order to be raised. As part of corrective action of the work order the technician provides as evidence the component related information/certificates. In case a certificate is not provided the engineer has to stop the activity and inform SC and Quality departments for the non-conformity. A finding of that magnitude could cause scheduled flights to be cancelled having adverse effects to an airline's reputation. That is the reason non-conforming products should be identified during the receiving inspection process. In the table below a summary of the certification documents requirements per status and source is depicted.

Table 2 Type of Part-Documentation Requirements

Type of Part	Source	Documentation for new status	Documentation for used status
Standard Parts	OEM	Certificate of Conformity (CoC)	

Materials (raw and/or consumables)	Third Party	• Certificate of Conformity (CoC) by OEM accompanied with a statement of the supplier source • Specification CoC (not OEM) accompanied with supporting documents providing traceability to the OEM and the supplier (e.g. ATA Form 106)	
Components		• EASA Form 1 • Equivalent release document issued by an organization under the terms of bilateral agreement with EU. (FAA Form 8130-3 with status new, TCCA Form 1 with status new, ANAC Form F-100-01 with status new.	• EASA Form 1 not issued by a CAO • Equivalent release document issued by an organization under the terms of bilateral agreement with EU 1. FAA Form 8130-3 with status overhaul/repaired/inspected issued by an EASA approved organization located in the USA with “dual release”: both boxes in block 14a are to be ticked and EASA release statement together with the EASA approval number are detailed in the remarks block. 2. TCCA Form 1 with status overhaul/repaired/inspected issued by an EASA approved organization located in Canada with “dual release”: both boxes in block 14a are to be ticked and EASA release statement together with the EASA approval number are detailed in the remarks block. 3. ANAC Form F-100-01 with status /repaired/inspected issued by an EASA approved organization located in Brazil with “dual release”: both boxes in block 18 are to be ticked and EASA release statement together with the EASA approval number are detailed in the remarks block.
	PMA	• For PMA part which is not a “critical component” the following statement should be written in the remarks block of FAA Form 8130-3: “This PMA part is not a critical component” • For a PMA part conforming to design data obtained under a licensing agreement from the TC or STC holder according to 14 CFR part 21 the following statement should be written in the remarks block of the FAA Form 8130-3: “Produced under licensing agreement from the holder of TC number xxxx or STC number xxxx”.	

		• If the PMA holder is also the holder of the EASA STC design approval which incorporates the PMA part into an EASA certified or validated product, the following statement should be written in the remarks block of the FAA Form 8130 3: "Produced by the holder of the EASA STC number xxxx".

Receiving Inspections

All components, standard parts and materials received either from any approved supplier, or pooled by the operator, shall be subject to receiving inspection procedure before such parts are released for storage and/or installation. The receiving inspection will be performed ad-hoc, whenever a part is delivered by the assigned on-duty certifying staff for the involved facility. An inspection checklist can be utilized to streamline the inspection process, imposing the following key steps:

- Physical inspection aspects: General condition, packaging, integrity, damages, corrosion, shelf-life verification (if applicable), ATA 300 requirements including ESD (if applicable), plugs, caps installed. Tape residues precaution. Special requirements for items in batches as defined above for the standard parts.
- Review of accompanying documentation aspects: Compliance with the purchase order/condition/quantity, compliance with regulatory certification requirements, modification standard and AD compliance, overhaul/repair records clearly indicate an approved/acceptable source, proper identification (description, P/N, S/N) verifying traceability of parts and materials physical data to the related documentation, eligibility for installation against the applicable maintenance data, special handling storage limitation and life limits identification.

Based on the incoming inspection results, the relevant parts will be routed to storage as per the following cases:

- Accepted Parts

Subject to satisfactory compliance of the above inspection, the relevant parts shall be deemed acceptable and handled as follows:

  - The receiving inspector (certifying staff on-duty) shall prepare a new serviceable part tag, by transferring pertinent data for the part (including LOT/batch number if applicable),
  - The serviceable part tag shall be attached to the original Authorized Release Certificate accompanying the part.
  - The part shall be routed to the serviceable storage area and recorded to the relevant tracking list.
  - A copy of the original Authorized Release Certificate with the purchase order and other pertinent documents shall be kept as records for future reference.

- Rejected Parts

If any non-conformances are identified that particular part shall be deemed unacceptable and handled as follow:

- The receiving inspector (certifying staff on-duty) shall prepare a Quarantine Material Tag along with a quarantine report and investigation form, by transferring pertinent data to the part.
- The rejected part shall be identified and routed to quarantine storage of the facility until final disposition. At this point quality assurance, engineering and SCM departments coordinate and based on the non-conformity nature decide the follow up actions (Supplier Non-Conformance Report, scrapping, internal NCR, concession request etc.)
- In addition the compliance monitoring manager will evaluate whether the rejected part falls within the Suspected Unapproved Parts conditions. In such case, he will submit a relevant occurrence report to the applicable aviation authority (EASA, FAA etc.)
- Copies of the relevant documents should also be retained to the applicable records for future reference.

Acceptance of Components in AOG situations

When an AOG condition persists, the required parts shall be delivered on the location that the aircraft has been grounded asap, potentially imposing maintenance outside from an approved location as per the MOE. In such cases the required parts may be delivered by the operator or sources other than the approved suppliers. Such parts shall be also subject to incoming inspection, prior installation, according to the procedures established above, under the ultimate responsibility of the assigned Certifying Staff that will issue the CRS for the aircraft. For non-approved suppliers the compliance monitoring manager shall additionally perform an assessment of the holding approval certifications prior the installation of the part.

Acceptance of Components from internal sources (between stations/bases)

When any components, standard parts and materials are being reallocated between approved stations/bases, a new incoming inspection is required at the receiving station's facilities.

Suspected Unapproved Parts Handling

Parts rejected during incoming inspection, especially when deviating from the certification requirements may potentially have been already declared as Suspected Unapproved Parts by EASA (EASA Suspected Unapproved Parts (SUP), n.d.). When in doubt about the origin of the part, the maintenance manager shall additionally consult the information reflected in the SUP list provided by EASA and/or FAA website, before accepting such a part into the store or before fitting it to an aircraft. If the part is verified as SUP already listed to EASA and/or FAA the part will be quarantined and reported to the compliance monitoring manager who shall submit a relevant occurrence report to EASA. If a part has been deemed eligible for SUP (fake certificate, stolen etc., although not included on EASA and/or FAA lists, will also be reported as per the above procedure.

Records

Historical records for the receiving inspection of any part shall be kept to the applicable station/base for a 3-year period. Such records should include authorized release certificates, purchase orders, incoming inspection results, rejected parts reports. These records should be available to the compliance monitoring manager when required, to impose positive feedback on the performance of the supplier during the recurrent evaluation or audit as applicable.

Installation of components/standard parts/materials

All components, standard parts and materials should only be installed when they are specified in the applicable maintenance data, including but not limited to aircraft parts catalogue (IPC), service bulletins (SBs), maintenance manual (AMM), parts information letter (PIL), component maintenance manuals (CMMs) and the same applies for the engines, auxiliary power units and propellers. Prior installation of any component/part on the aircraft the Certifying Staff shall ensure that the routed for installation part has been subjected to satisfactory incoming inspection and was properly stored, packaged and tagged, is eligible to be fitted when different modification and/or airworthiness directive standards may be applicable, is in satisfactory condition and accompanied with appropriate certification documentation and a serviceable tag, the shelf life and/or service life if applicable are not expired. Following the installation, the certifying staff issuing the CRS will attach the certification document and the serviceable tag, properly fulfilled with the aircraft information to the work order package.

2.2. Digitalization in the Supply Chain

During the last 30 years, a major shift occurred on logistics, from an operational function reported to other departments to ensure deliverables to the customers, to an independent management function, leading to advanced planning, sourcing, operational processes, ensuring integrated operations from customers to suppliers(*Supply Chain 4.0 – the next-Generation Digital Supply Chain*, n.d.). Digitalization or digitization is the process of converting information into digital format. The result may be the representation of a document, image, signal obtained by a series of numbers that describe a discrete set of samples (*Digitization*, n.d.). Supply chain digitization is the process of replacing manual or analog processes throughout the whole spectrum of SC, with digital equivalents. Digitization can be used as a transformational tool of SCs with the aim to incorporate digital technology into multiple supply chain activities. Digital transformation propels organizations towards a more networked and flatter structural evolution. Furthermore it aids businesses in transitioning from a traditional supply-driven model to a demand-driven model(Pingrui, n.d.). Factors such as globalization, technological advancements, consumer demands, regulatory requirements and emphasis on sustainability are acting as catalytic agents making a necessity to further optimize the existing SCs. Leveraging tools such as advanced analytics, blockchain and IoT sensors, in a methodic way, can enhance traceability and efficiency while ensuring compliance with stricter regulations. To meet the expectations of today, the transition to Industry 4.0 is of highly importance.

2.2.1. Supply Chain 4.0-Industry 4.0

Supply chain 4.0 can be considered the application of the Industry 4.0 idea. Industry 4.0, also known as the Fourth Industrial Revolution, refers to the integration of digital technologies into manufacturing and supply chains to create smart interconnected systems. The main goal of digitization in SC is to remove human errors from every part of the process by utilizing all the applicable technological tools. Some of the main innovative technologies that will integrate and make the digital SC possible are, Big Data, cloud computing, augmented reality, artificial intelligence/ machine learning, cyber-physical systems, autonomous robots, IoT, smart contracts and blockchain (*Towards the Adoption of Industry 4.0 Technologies in the Digitalization of Manufacturing Supply Chain*, n.d.). In the following paragraphs a brief introduction to the above-mentioned technologies is presented:

- Internet of Things (IoT): While digging into the concept of digital SCs, one of the primary pillars is the IoT and its role in fostering connectivity across all stages of the SC. IoT serves as the foundation for orchestrating the various robots, machineries and hardware components within SC, permitting seamless communication and autonomous coordination of tasks among them. Acting as a link between physical and digital world, IoT facilitates a network where free information flow is enabled. In manufacturing, swift diagnosis of production halts, immediate problem-solving responses, additional situational awareness are some of the implementation outcomes. In the aviation SC the integration of IoT offers immense potential for enhancement, by leveraging IoT-enables sensors and tracking mechanisms, transparency, traceability and real time monitoring, throughout the entire lifecycle of aircraft components. Due to this reason researchers have proposed employing the technology with radio frequency identification (RFID) tags, however, a myriad of problems is surfacing, including airworthiness document racking, information security, access rights etc. (Ho et al., 2021).

- Big Data and Analysis: In the era of fully digitalized SCs, copious amounts of data are continuously generated and stored across the network's digital systems. This data repository is vital for boosting SC performance as the landscape increasingly relies on data-driven insights. Through comprehensive analysis, this wealth of data empowers both process-level optimizations and main strategic decisions, facilitating superior business analytics and planning within the SC ecosystem. SC analytics opportunities can be realized in all SC levels and processes including: Planning, sourcing, production, warehousing, transportation, point-of-sale, consumer. Although, in accordance with there is a huge space for improvement of BDA application in SC management in the following aspects: More attention to big data analysis is a must in the manufacturing and procurement stages, SC players should work together to create a viable and sound placement of BDA, before processing the data, the accumulated data shall be jointly prepared and grouped by all SC actors. Open communication is a paramount between all the stakeholders for more clever use of BDA and less costs (*Insights from Big Data Analytics in Supply Chain Management: An All-Inclusive Literature Review Using the SCOR Model*, n.d.).

- Cloud Computing: In the realm of SCM, maintaining robust networking, software infrastructure and analytical capabilities is of highly importance. The enormous amount of big data generated by SC operations makes necessary efficient storage, processing and accessibility. Traditional approaches, such as storing data on local servers, require significant maintenance costs. To address these concerns, cloud computing emerges as an interesting solution. It offers a combination of computing services delivered thru the internet and making possible swift access to resources, adaptable SCM and economies of scale. Fig.1 depicts a cloud-based self-thinking SC model. There is a high degree of connectivity between cyber systems and objects through the use of IoT. Huge amount of data is generated and analyzed by IoT and AI and this data efficiently managed with the cloud computing contribution. Therefore, the combination of these technologies allows real-time connectivity, and integration starting from the suppliers until the final destination of the products which is the customer (Calatayud et al., n.d.). On (*Cloud Service Composition of Collaborative Manufacturing in Main Manufacturer-Suppliers Mode for Aviation Equipment*, n.d.) it's stated, to realize an well-organized relationship between the main aircraft manufacturers and the suppliers regarding resources, businesses and processes, cloud platforms are increasingly applied to the joint manufacturing of complex products.

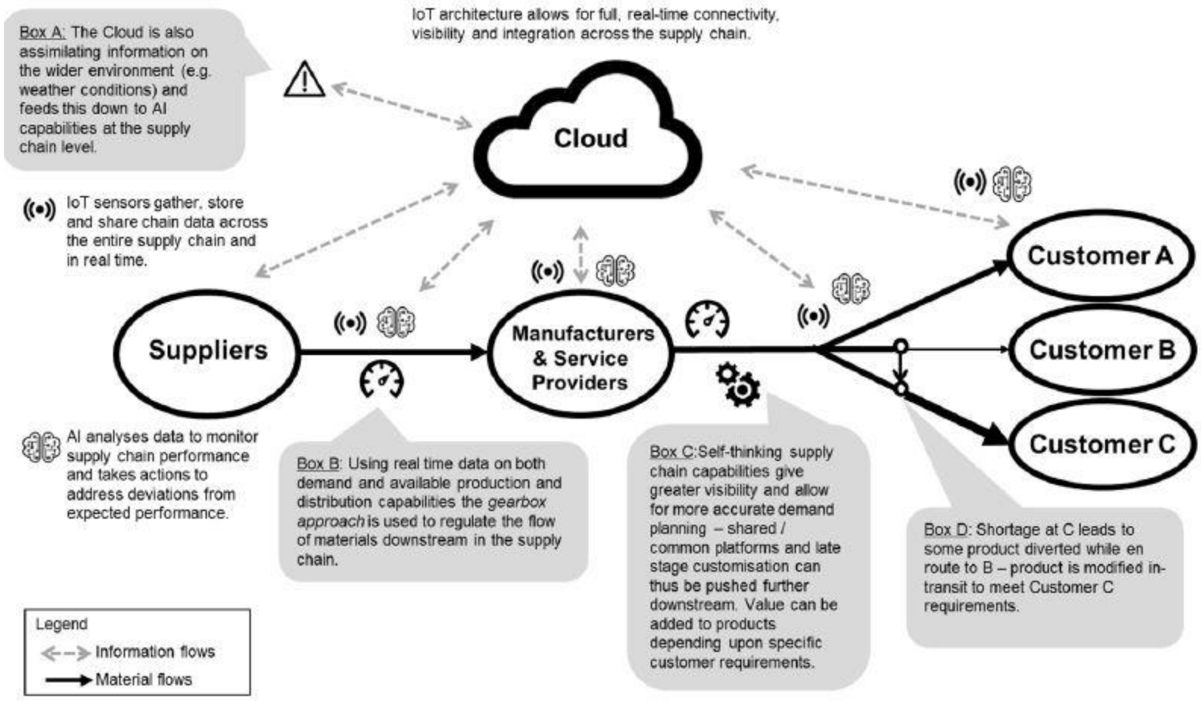

Figure 1 Cloud-based self-thinking supply chain (Source (Calatayud et al., n.d.))

- Artificial Intelligence/ Machine Learning: By definition artificial intelligence refers to the development of computer systems able to perform tasks that normally require human intelligence. Some examples may be speech recognition, decision-making, visual perception etc. Machine learning is a field of study in AI responsible for the development and study of algorithms that can learn from data thus perform tasks without explicit programming. On (*Demand Forecasting for Irregular Demands in Business Aircraft Spare Parts Supply Chains by Using Artificial Intelligence (AI)*, n.d.), an example of a possible usage of AI in the aviation industry is proposed for spare parts forecasting optimization on business aircrafts. Due to the unknown operational profiles of these aircrafts and data restrictions it's overwhelming to accurately predict the demand of those parts, resulting in extended grounding times and operational interruptions.

- Cyber-Physical Systems: CPS are a combination of computation with physical processes. They blend physical components with software enabling them to work in hand with humans. By the addition of digital features to these systems a new world of managing supply chains is created. Every component that is operating within any process of the SC is part of one network and close monitoring of all the actions is enabled, therefore allowing for the proper and on time interference of management. As per (*Synchronizing and Improving Supply Chains through the Application of Cyber-Physical Systems*, n.d.), CPS are usually closed loop systems, with sensors making measurements of physical tasks and following that the measurements are processed in the cyber subsystems, which drive actuators that alter physical tasks. The control strategies employed in the cyber systems shall be adaptive and predictive. From the two scenarios examined, the second one with CPS embedded, indicated an improved performance of the SC in terms of service level and flexibility.

- Industrial Robots: Robots have their own role in supply chain transformation. From robotic arms to drones and guided vehicles. The pros and cons of robot's integration in the SCs is summarized to the following table:

Table 3 Robots in SCM-Pros and Cons

Advantages	Drawbacks
Repetitive tasks with precision and speed, working 24/7.	High upfront costs.
Reduce labor costs in long run.	Malfunctions may lead to SC interruptions and additional costs.
Perform tasks with high quality, keeping away defects and errors from the processes.	In comparison with human workers robots lack the adaptability and problem-solving skills.
Perform dangerous tasks for humans eliminating safety risks.	Their adoption may lead to human unemployment, especially for unskilled workers.
Efficient manage of inventory, optimize storage space.	Prone to cyber-attacks.

- Blockchain and Smart Contracts: In the next section we are focusing on blockchain technology and therefore smart contracts, although as an important tool of Industry 4.0. we are providing, on this paragraph a brief introduction of this tool capabilities and possible uses to SCs. Blockchain technology is useful in a variety of fields healthcare, financial sector, etc. although we can tell SC will the most affected sector. New horizons introduced including flexible payment methods due to the decentralized nature of blockchain, records almost impossible to alter are stored in the blockchain and protected by cryptography, effective monitoring of processes is enabled due to the availability of huge data, origin of products and record of ownership is available to the respective stakeholders (*Role of Blockchain-Oriented Smart Contract in Supply Chain*, n.d.).

2.2.2. Industry 5.0

Industry 5.0 builds upon the foundation of Industry 4.0 but emphasizes on human-machine collaboration and interaction. It utilizes the same technologies with Industry 4.0 and focuses on enhancement of workers capabilities to enable the best possible outputs of collaboration between humans and machines. Industry 5.0 is bringing back workers into manufacturing actively being part of the production process. Sustainable SC performance is being implemented and verifiable due to the technical improvements and we should not forget the reinforcement of ethical sourcing (*A Structural Equation Modeling Framework for Exploring the Industry 5.0 and Sustainable Supply Chain Determinants*, n.d.).

2.2.3. Aviation 4.0

On Aviation industry an emphasis is given to the implementation of new technologies to improve maintenance activities. The main reason is the unwarranted maintenance costs, especially when maintenance is reactive. In general, there are two different maintenance strategies, reactive or proactive. Proactive maintenance is further divided in preventive and predictive maintenance. Figure 2 depicts the existing maintenance strategies.

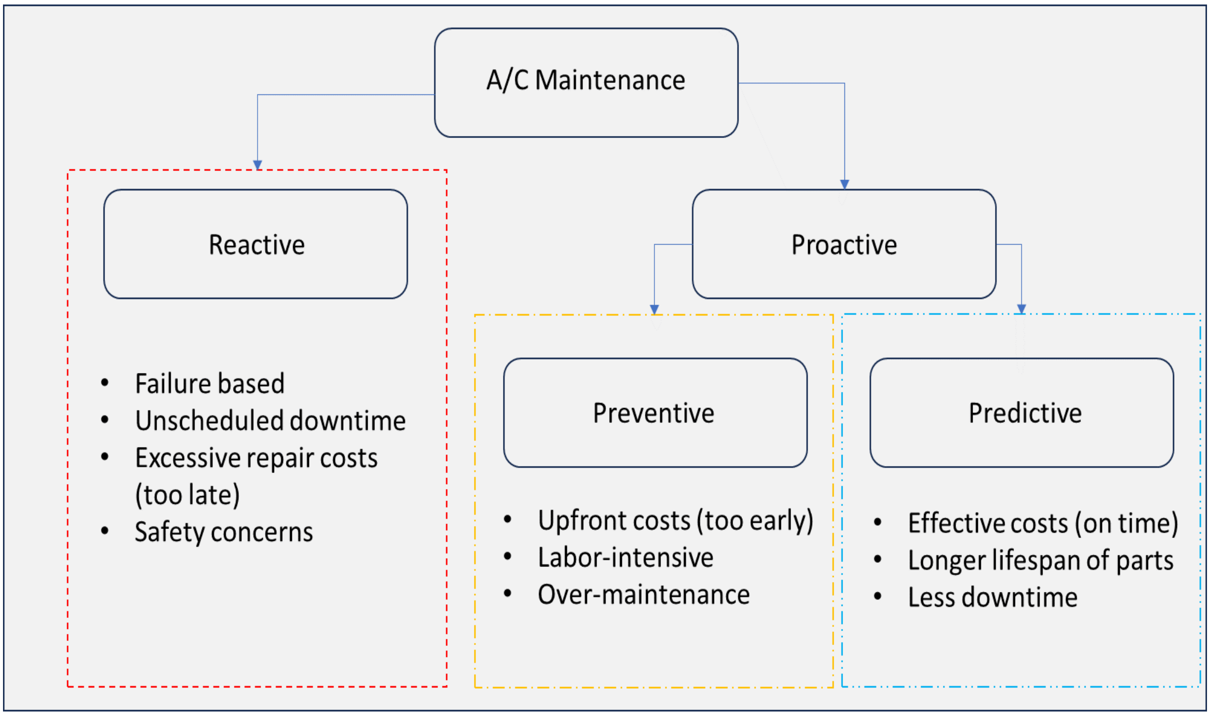

Figure 2 A/C Maintenance Strategies

As a strategy preventive maintenance is established from the early 1970 and concepts such as production costs, material life are well established in the industry. At present, we are in the era of Industry 4.0 and we are discussing about the transition to Industry 5.0. Therefore, predictive maintenance was introduced, including risk management, renewable energy sources etc. Predictive maintenance, already is implemented across the industry and in Hellenic Air Force with the procurement of fighter A/Cs Rafale as well as the 5th generation F-35 which is expected to be included in the operational fleet in the near future. Health monitoring systems are utilized whenever it is required and provided by the OEMs, there are numerous examples of health monitoring systems especially embedded in the most critical and highly importance components (engines, APUs etc.). Predictive maintenance combines the benefits of preventive and reactive maintenance and is based on a set of new technological fields such as artificial intelligence, machine learning and artificial neural networks. Impending failures can be detected in time so appropriate maintenance actions can be performed on time avoiding excessive repair costs. The goal is to perform maintenance only when it is necessary, avoiding failures that are capable to degrade the systems. The technologies commonly used are vibration analysis, oil sampling, ultrasounds, SFDR recordings evaluation etc.

2.3. Blockchain

Introduction to Blockchain Technology: Since Bitcoin's debut in 2008, blockchain is gaining increasing scientific and industrial interest. Bitcoin is the most popular cryptocurrency using Blockchain, the most known distributed ledger until today (*Blockchain Implementations and Use Cases for Supply Chains-A Survey*, n.d.). Blockchain utilizes a combination of distributed systems, cryptography, peer-to-peer networks, etc. to provide a network of trust to allow information to be validated and saved in a network with public access in which deleting information already stored is not an option. On this section a brief explanation of the implementation architecture of blockchain technology is presented.

To begin with, in blockchain architecture, there are six different layers: data, network, consensus, incentive, contract and application.

Data layer

Data layer includes the data blocks. Each of those blocks are timestamped and encoded by a hash. Cryptographic hash functions create digital fingerprints for all forms of data. The blocks are composed by a block header and body. Every block connects to the other by utilizing hash function. To have a proper pattern for the hash, Nonce number is generated. The transaction of each individual block is stored in the Merkle root based on Merkle tree mechanism. The block body encompasses the hashes and the transactions of the specific block. Cryptographic Hash in plain words is the digital equivalent of fingerprints and it is a specific category of Hash functions. Cryptographic hash functions exhibit specific properties and their application to data can be accomplished by using different patterns. It is considered out of scope of the current thesis to elaborate further on Hash functions.

Network layer

The network layer as the second layer of BCT is distributing, authenticating and moving the transactions forward. Out of the two network architectures which are Client server and Peer-to-Peer, blockchain utilizes the Peer-to-Peer. In the P2P framework several nodes are communicating the transaction data with the aim to reach an agreement on the transaction's validity. To achieve that the prerequisite is that all the nodes shall be able to find other nodes and this communication between the nodes is made possible by the network layer. The following functions are managed within the network layer, node recognition, block generation and addition.

Consensus layer

This layer is of highly importance in the blockchain networks and the reason of its creation is to achieve an agreement among all the BCT participants on either to accept or decline a transaction. It is a precondition to establish a well-organized decentralized institution. Some of the main consensus mechanisms are listed below:
Proof of Work,

Proof of Stake,
Practical Byzantine Fault Tolerance,
Delegated Proof of Stake,
Proof of Burn,
Proof of Capacity,
Proof of Elapsed Time etc.

There is a plethora of consensus mechanisms, all in all it is important to select the most appropriate for the business network requirement, having in mind that a network is not functional and trustworthy in case it is not capable to verify each and every transaction. It is noted, the proof of work is the most known algorithm and the main reason is that Bitcoin is utilizing this algorithm. The main idea behind this algorithm is to solve a complex mathematical puzzle and provide the solution. The node which solves the puzzle is the one mining the next block. Computational power is required for these calculations and this is the main reason leading computer scientists to believe that if one entity is able to accumulate huge computational power, the same entity could possibly influence the consensus at its own benefit. Therefore, different algorithms came into play, each one with associated advantages and disadvantages. A major concern with the introduction of the alternative mechanisms is that they are usually complicated and lack of formal approval. In case of a flaw in such mechanisms, corruption of the blockchain may occur.

Incentive layer

The incentive layer is acting as the motivational tool, rewarding the nodes participating in the creation of new blocks with economic incentives (digital currencies). The rewards are allocated according to each node contribution.

Contract layer

The fifth layer of the blockchain technology is the contract layer. Within this layer complicated transactions are enabled by the utilization of scripts, algorithms and smart contracts. Similarly to the transactions, smart contracts are computer-readable descriptions of the will of the involved parties. The main difference is that smart contracts present more flexibility regarding the objects, subjects, actions and conditions used to describe the transfer of ownership (DRESCHER, n.d.). The rules and regulations enabling the parties of a contract to cooperate and make transactions. Following the establishment of a smart contract, the contract provisions are encrypted and approved by the respective parties. After establishing the contract between the parties and finalizing the rules, all the provisions of the contract are encrypted and approved by the parties, following that, the smart contracts are forwarded to the rest of the blockchain. The blockchain is updated when the transaction is completed and the transaction cannot be changed. Only the parties with permission can see the results.

Application layer

All the functions related with the final user needs potentially could be referred as application layer. All the above-mentioned layers could be part of the implementation layer and considered as means to an end. The uppermost layer composed of business applications, such as digital identity, IoTs, deep learning, industry 4.0, smart grids, intellectual property etc. Academics and industry are making efforts to apply this promising technology into a large number of industries including SC.

Blockchain classification - nodes authority

Based on the different authority levels of nodes in the consensus mechanism the blockchains are categorized as public, alliance and private chains. Public chains are permissionless all the users can read, forward transactions, be part of the consensus process and preserve data on the blockchain. Bitcoin is a characteristic example of this type of chain. Consortium or alliance chains are unions of public and private blockchains and a node needs authorization to participate on the chain. In these types of chains there are some controlling nodes verifying and validating blocks and transactions. It is appropriate for certain users or enterprises with confidential information exchange. IBM Food Trust is an example of consortium blockchain. The private chain is restrictive and there is a center entity approving the activities taking place within. In this case nodes have limited and specific rights.

Applications of Blockchain in Aviation

Theoretically there are potential blockchain use cases in aviation industry, as it is presented on (Pinto Lopes et al., n.d.), some of those cases are Maintenance management, Identity Management, SCM, Payments etc. Air transport professionals working in innovation and business intelligence departments were interviewees on that research. The result of the thematic data analysis shows that those individuals focused on the costs reduction and the potential competitive advantages of the implementation of such a technology. The conclusion of the study is that expectations are higher than the acknowledgement of what blockchain can bring. There is a believe that blockchain is still not mature enough to be implemented in large scale. There are more wants from the specific industry than actual efforts to change the current status. A few airlines performed some blockchain trials with different aims although none of those is explicitly standardized. It is noted that Etihad Airways tested distributed ledger technology for internal inventory management. A study conducted to identify opportunities of blockchain implementation in aerospace and defense sector (Wasim Ahmad et al., n.d.), clarifies that SCM manages a vast number of aircraft parts, dozens of parameters related to each part and hundreds of suppliers located in different locations across the globe. The current approaches used for parts transactions are not fully capable to enhance planning of the procurement, due to lack of traceability and transparency. An initial stage blockchain framework is proposed for aircraft engine parts SCM. Key applications of smart contracts implementation on the industry, are mentioned as for example transaction settlement, operations audit, secure shipment, prevention of compliance violation, identification of counterfeit parts, reliable additive manufacturing, enforcement of tariff and trading policies etc. On another study (Mandolla et al., n.d.), emphasis is given on the importance of a digital twin in production phase of aviation products, especially for Additive Manufacturing supply chains. A conceptual answer is provided to securing and organizing data generated through the whole process, by utilizing the potential of Blockchain technology. Companies holding a Production Organization Approval could benefit from an inclusion of the proposed framework. By doing that, those organizations could streamline the auditing procedure performed by the national agencies and be able to present historical records for each individual product across all the phases of the production and entities of the company involved from design to quality verification and release. Research (PENGYONG et al., n.d.) has shown that integrating blockchain technology with manufacturing supply chain quality management can effectively address challenges in aviation supplier data sharing. A blockchain-based intelligent sharing platform of process quality data for aviation suppliers is presented, with details for each layer and solutions for the following obstacles are proposed:

- How to produce quality data on the blockchain, implementation of step-by-step storage and safety sharing,
- As the volume of block data grows, the blockchain faces challenges related to the storage capacity, scalability,
- Increased data interactions on the chain can lead to response delay issues as the amount of data continues to rise.

Finally, a blockchain-based system to enhance aircraft parts traceability is presented by (Ho et al., 2021), an executive platform, for recording of spare parts traceability data with organizational consensus and validation using Hyperledger Fabric and Hyperledger Composer, is created and tested. Due to the fact that the specific research is closely related with the subject of the current thesis, providing valuable insights a more detailed information from this paper is provided herein. To create a realistic scenario a representative sample of organizational parties involved in the aircraft parts management were considered including the original equipment manufacturers (OEMs), Maintenance and Repair Overhaul organizations (MROs), airlines, and logistics service providers. The parts possible flows between the parties were taken into account and the organizational relationships have been appreciated. Regarding the traceability information set applied in developing smart contracts a thorough planning is required to consider all the key factors that influence the operations and safeguarding continuous monitoring. Information from each stage of a part shall be recorded starting from manufacturing phase. The decision on what information is vital and should be listed shall be determined by the regulatory framework and agreements between the parties. The information set may include the following: P/N, S/N, Part description, Time since New (TSN), Cycles since New (CSN), Life limits, Remaining Hours/Cycles, Part History of Removals/Installations, Configuration information, process information, quality information, supporting documents etc. It is out of the scope of this document to describe the exact principle of design of the proposed framework, the important part is that by implementing it, the clients are eligible to perform transactions and HTTP requests in an efficient manner as it is proved by the sensitivity analysis conducted and in the same time restricted information is not accessible to unauthorized parties of the system. Before the implementation of such a solution, its pilot application is proposed for all the different categories of aviation parts among all the representative parties, alongside the traditional recording methods utilizing legacy systems and human interaction.

Honeywell's GoDirect Trade

Honeywell's GoDirect Trade represents a pioneering implementation of blockchain technology in the aviation aftermarket, transforming how used serviceable and surplus parts are traded (Honeywell's GoDirect™ Trade Leverages Blockchain to Overhaul Aircraft Parts Aftermarket, n.d.). Recognizing the sector's critical need for trust, transparency and traceability this platform was developed as a blockchain enabled e-commerce marketplace. The platform ensures secure transactions by recording detailed part histories, including repair events, dismantling records certification documents, on an immutable distributed ledger. Built on Hyperledger Fabric with proprietary middleware, the system integrates seamlessly with Honeywell's enterprise resource planning (ERP) system, enabling real time updates from its global network of repair facilities. The marketplace supports multiple blockchain protocols like Ethereum and Corda to maximize interoperability. This digital ecosystem reduces reliance on traditional email and phone-based transactions, cutting search-to-purchase times while fostering industry wide collaboration. By coupling blockchain with anti-counterfeit technologies such us Trust Trace, Honeywell has established a robust standard for provenance management, paving the way for a more transparent and secure aviation supply chain.

The exploration of the present spare parts management issues facing the aviation sector has brought to light the urgent need for cutting-edge solutions that guarantee efficiency, traceability, and compliance in ever-more complicated supply chains. Although chapter 2 covered the fundamentals of the evaluation and procurement of spare parts as well as the revolutionary impact that digitization has had in streamlining operations, it also highlighted the growing interest in blockchain technology as a possible facilitator of these advancements. Building on this foundation, chapter 3 explores in greater detail the particular uses of blockchain technology in spare parts management, using knowledge from previous research to provide a thorough grasp of its potential. In order to close the gap between theoretical possibilities and real-world applications, this review lays the groundwork for comparing these discoveries with the analysis's results in subsequent chapter 5.

CHAPTER 3-Literature Review-Blockchain Technology for the Management of Aircraft Spare Parts

Managing spare parts remains a challenge for the aviation industry, which is renowned for its complexity and strict regulatory requirements. These challenges include opaque multi-tiered supply networks, inefficient spare component tracking, and the proliferation of counterfeit parts. Blockchain technology offers a revolutionary answer to these problems with its decentralized, immutable, and transparent ledger properties. By providing an immutable record of transactions, blockchain may increase stakeholder trust, ensure compliance with stringent rules, and accelerate operational efficiency. With an emphasis on the results of eleven studies that specifically address aviation-related issues, this chapter investigates the use of blockchain technology in the administration of aircraft spare parts.

3.1. Blockchain Technology for Aviation Spare Parts Management

3.1.1. The “Avipar-Chain”, Blockchain for aviation MRO operations

(Richardo et al., 2022) introduced the "Avipar-Chain," a blockchain-based solution created specifically for aviation Maintenance, Repair, and Overhaul (MRO) operations. The application uses Hyperledger fabric to implement a permissioned blockchain making sure that only authorized parties can access classified information. The research used an incremental development model, with phases (requirement gathering, design, development, testing). The application design allows users to interact with the blockchain through a web interface. This study highlighted significant problems such the use of manual documentation prone to errors, operational inefficiencies, lack of trust among parties and the absence of traceability in the management of spare parts. The study demonstrated how blockchain technology significantly improved stakeholder confidence and data integrity. The system's role-based access control and real-time status updates addressed inefficiencies in spare component management and monitoring, ensuring regulatory compliance. Additionally, "Avipar-Chain" facilitated smooth collaboration between manufacturers, suppliers, and maintenance firms, reducing delays and boosting output. Various functionalities are available tailored to the roles of different stakeholders. As an example, manufacturers can create and update spare parts records, vendors can purchase and manage inventory, MROs can handle maintenance requests and spare parts repairs and airlines can track the history and status of parts used in their fleets.

3.1.2. Blockchain for managing civil aircraft components

This paper (Milovanov & Nasonov, 2024) focused on the application of blockchain technology in aviation supply chains, namely for the management of civil aircraft components. The authors highlight the challenges faced by aviation supply chains, like simultaneous operation of counterfeit components with identical serial numbers and the falsification of documentation. Their analysis emphasized the value of blockchain in maintaining comprehensive maintenance records and guaranteeing traceability. The integration of blockchain technology with RFID systems was highlighted as a way to enhance operational efficiency and logistics. Examples from the real world, such US Department of Defense research and Air France-KLM pilot programs, demonstrated how blockchain might improve data security, speed up component delivery, and ensure safety requirements are followed. The researchers discovered that blockchain's ability to create an immutable record of each transaction significantly reduces the likelihood of counterfeit parts entering the supply chain.

3.1.3. Addressing counterfeits and transparency in multi-tier supply chains

This paper (Madhwal & Panfilov, 2017) looked into the intricacies of supply chains for airplane replacement parts and found that blockchain could be a viable solution to improve authenticity and transparency. The study addressed important topics like the potential for counterfeit parts and inefficient multi-tier supplier networks. In detail supply chains involve multiple tiers, ranging from small scale component manufacturers to large scale original equipment manufacturers. These networks are prone to issues like lack of visibility beyond the second tiers and limited control over sub-suppliers which can lead to counterfeit parts entering the market. By implementing a decentralized, impenetrable record, the researchers demonstrated how blockchain technology may enhance supply chain performance and ensure compliance with stringent aviation regulations. Their findings showed how important blockchain technology is for increasing stakeholder trust, reducing operational inefficiencies, and enhancing system reliability overall. The potential of blockchain to serve as a global inventory registry, maintaining detailed records of parts production, assembly, and maintenance history is also discussed. During overhauls or routine maintenance, engineers can access this information to verify part authenticity and ensure compliance with regulations. Costs related with fraud, delays and manual paperwork could be reduced.

3.1.4. Improving inefficiencies in aviation maintenance

Blockchain's potential to alleviate inefficiencies in aviation maintenance and repair operations was investigated by (Efthymiou et al., 2022). The transformational potential of blockchain technology in the aviation sector is examined as part of this research, with a focus on improving data integrity and supply chain traceability. It highlights how blockchain may enhance component tracking, maintenance records, and regulatory compliance while addressing current inefficiencies including manual processes, inconsistent record-keeping, and restricted data openness. Significant adoption barriers are highlighted in the study, though, such as the difficulty of integrating blockchain with current enterprise systems, the high upfront and ongoing costs, stakeholder resistance brought on by ignorance and cultural inertia, and regulatory ambiguities brought on by a lack of standardized guidelines. Notwithstanding these obstacles, the study emphasizes the value of pilot programs to confirm blockchain's viability and boost stakeholder trust, as well as cooperative initiatives between regulators, operators, and manufacturers to create standardized protocols. In order to fill up knowledge gaps and highlight the long-term advantages of blockchain, educational programs are advised. Future studies should also look into scalability improvements, regulatory frameworks, and the results of empirical pilot projects. The report recognizes the immaturity of blockchain implementation in aviation and urges more work to close this gap, despite the fact that it is primarily theoretical and reflects industry expectations. Efthymiou makes a strong case for blockchain integration by addressing use cases unique to the aviation industry and aligning with the body of research on the technology's transformative potential as long as the technological, financial, and cultural barriers are methodically removed.

3.1.5. NFT-Based Component lifecycle management

In order to manage the lifecycle of airplane components, (Kabashkin, 2024) suggested a novel NFT-based system that combines blockchain and digital twin technologies. The framework supports aviation's transition to data-driven operations by offering predictive maintenance and real-time monitoring features. In order to transform aircraft component lifecycle management, Kabashkin's research offers a revolutionary paradigm that combines digital twin technology with Non-Fungible Tokens (NFTs). The system guarantees thorough traceability, authenticity, and data integrity throughout a component's lifecycle, which includes production, certification, maintenance, supply chain management, and retirement, by allocating distinct, unchangeable blockchain-based NFTs to physical components. As dynamic digital equivalents of physical assets, NFTs are updated in real time to reflect shifts in ownership, performance, and condition. Through tamper-proof records, this integration facilitates operational efficiency, improved predictive maintenance, and adherence to strict aviation rules. The study examines a number of workflows, such as flight logs, regulatory certification, part tracking, maintenance record management, and quality assurance, and shows how NFTs enable smooth data exchange between stakeholders while lowering risks like fake parts and ineffective inventory control. To further increase efficiency, smart contracts automate vital procedures like ownership transfers and compliance checks. In addition to making audits and regulatory compliance easier, the combination of blockchain and digital twin technologies promotes sustainability by providing comprehensive end-of-life records for component recycling and repurposing. Kabashkin discusses the difficulties in putting such a system into place, such as the difficulty of connecting blockchain with legacy systems, the high upfront costs, the difficulties in obtaining regulatory permission, and the technological requirements of securely and effectively maintaining large datasets. The framework presents substantial chances for improved safety, cost savings, operational transparency, and stakeholder cooperation in spite of these obstacles. In order to facilitate the broad use of NFT-based systems in aviation, the study ends with a suggestion for more research on blockchain scalability, AI-driven predictive analytics, interoperability standards, and regulatory frameworks. NFTs and digital twins are positioned by Kabashkin's work as key technology for the digital transformation of aviation, offering a path to a more sustainable and safer sector.

3.1.6. Safeguarding maintenance records with blockchain

The safeguard Aircraft Maintenance Records (SAMR) system was presented in this research(Aleshi et al., 2019) in which blockchain technology was used to digitize and safeguard maintenance records. Through tamper-proof data and real-time accessibility for stakeholders, the system guarantees FAA compliance. By lowering the risks of lost or fabricated records, the SAMR system improves operational safety and transparency. This scalable system demonstrates how blockchain may be used in a variety of aviation sectors, making it an essential tool for updating maintenance management procedures. The SAMR architecture uses a blockchain-based system created with Hyperledger Sawtooth, which uses the Proof of Elapsed Time (PoET) consensus algorithm and SHA-512 for data hashing. Operational continuity and FAA compliance depend on the immutable, tamper-proof storage of maintenance records, which SAMR guarantees by switching from physical logbooks to a distributed digital ledger. Key characteristics of the SAMR system are highlighted in the article, such as modular adaptability for changing aviation requirements, transparency for stakeholders like the FAA and NTSB, and reliability through distributed nodes. To reduce risks like data manipulation and illegal access, it integrates digital signatures, permission-based access control, and threat modeling (STRIDE). The system's real-world implementation is illustrated through a simulation scenario, which shows how safe digital records lower the risk of fraud and expedite audits while maintaining compliance. Aleshi's work demonstrates how blockchain technology can revolutionize aviation recordkeeping by facilitating secure part tracking, long-term data integrity, and operational efficiency. It ends by confirming that the SAMR blockchain complies with FAA regulations and recommending more study on security improvements and wider industry usage. This strategy ensures safer and more dependable aircraft operations by marking a advancement in updating aviation's documentation procedures.

3.1.7. Improving supplier collaboration with blockchain

A blockchain-based supplier quality data sharing network specifically designed for the aviation industry was created and presented (PENGYONG et al., n.d.). With an emphasis on removing data silos, boosting information credibility, and encouraging effective cooperation, the study presents a blockchain-based platform to address issues with high-quality data exchange across aviation vendors. The platform creates a safe, decentralized environment for data sharing and storage by integrating blockchain technology with supplier quality control systems. Reliable traceability, tamper-proof data storage, and real-time access are guaranteed by its multi-layer architecture, which consists of layers for data collecting, structuring, storage, blockchain, and applications. A manufacturing quality data block packaging model for structured data management, a supplier evaluation mechanism for maximizing supplier selection based on quality metrics, and a hybrid on-chain/off-chain storage approach that preserves the security and scalability of large datasets are some of the key innovations. Additionally, the platform uses smart contracts to manage access restriction and data verification, guaranteeing smooth supplier and aviation company collaboration. Through real-world examples, the paper illustrates useful applications, such as statistical process control (SPC) for product quality monitoring and dynamic data gathering employing RFID technology. It emphasizes how easily the system can evaluate suppliers, lower the danger of information asymmetry, and increase the efficiency and transparency of the supply chain. The study concludes with a roadmap for integrating other data modules (such as logistics and cost management), positioning blockchain as a game-changing technology to improve aviation supplier collaboration and management.

3.1.8. Blockchain for aircraft maintenance data

A blockchain-enabled system for tracking aviation maintenance records with a focus on compliance and traceability was presented by (Andrei et al., 2021). The study showed how blockchain provides stakeholders with safe and easily available maintenance records while increasing data accuracy and decreasing documentation errors. Compatibility with current ERP systems and other integration issues were identified as major obstacles to broad adoption. This paper presents a blockchain-based solution for aircraft maintenance data. The study draws attention to the difficulties in handling massive amounts of maintenance data, which are essential for guaranteeing safety, regulatory compliance, and airworthiness. The suggested blockchain approach uses a decentralized, impenetrable digital ledger in place of conventional, prone to errors, paper-based techniques. In order to maintain transparency and trust, this ledger enables real-time, secure access to and sharing of data by all parties involved, including manufacturers, airlines, maintenance companies, and regulatory bodies. The article details the creation of a proof-of-concept blockchain application in Python that incorporates important functionalities including smart contracts, immutable data, and decentralized consensus mechanisms like Proof of Work. Smart contracts and cryptographic security features like SHA256 are incorporated into the blockchain design to automate necessary tasks like maintenance inspections, guaranteeing adherence to operational specifications and lowering the possibility of overdue tasks. By offering a solid data base for AI-driven analytics, the system also facilitates predictive maintenance, which can lower unscheduled downtime and improve operational effectiveness. Andrei highlights how blockchain technology in aviation may boost consumer confidence, streamline audits, and create safe and accessible data, among other commercial and safety advantages. The study shows how flight and maintenance events are tracked and verified using a small-scale application to illustrate the blockchain's capability. In order to change aircraft maintenance procedures, it ends by urging industry adoption and further development of blockchain technologies. It emphasizes how these systems might lower safety incidents and improve operational trust in a sector that is growing quickly.

3.1.9. Spare parts procurement and monitoring

A blockchain-based cooperation system was presented as part of this research (Z. Zhang & Xi, 2021) to improve the procurement procedures for spare parts. Their SaaS-integrated architecture guaranteed transaction transparency and allowed for real-time data exchange. Blockchain's ability to simplify processes and lessen reliance on middlemen was illustrated by the system's usage of smart contracts to automate procurement workflows. In detail Zhibin Zhang and Jianqing Xi describe a blockchain-based organization collaboration system for the procurement of spare parts that uses Hyperledger Fabric and the Software as a Service (SaaS) architecture to solve concerns about efficiency, security, and trust in data sharing across businesses. The study refers to the drawbacks of the commonly used systems. In detail their dependence on external management and the high possibility of data manipulation are mentioned and the blockchain technology is suggested due to the decentralized and impenetrable characteristics, as a safe way to handle cooperation records. As part of the suggested system design, peer nodes to be used for blockchain data storage, ordering services for transactions processing and organizations with databases and apps for cooperation are proposed. To introduce more flexibility to a plethora of business scenarios, the collaboration logs are kept as structured data within the blockchain. JSON formats are used and unique identities. To further improve system function, smart contracts are used to enable automation of log creation and querying. The system's viability is shown by performance tests that are performed on virtual machines. When the maximum message count parameter is set to about 150, the system achieves optimal transaction throughput (TPS) for both query and create operations. This attests to the effectiveness of the suggested design and the consensus process that fortifies it (etcdraft). According to the study's findings, blockchain-based solutions may improve transparency between organizations and strengthen partnerships. Moreover, data security is achieved while also a scalable and also modular architecture appropriate for complicated procurement scenarios cam be achieved. The technology will be expanded in future research to accommodate a greater range of industries and collaboration methods. A blockchain-based architecture was presented by (Ho et al., 2021), to enhance the traceability of aircraft spare parts. The usage of Hyperledger Fabric in parallel with IoT is proposed for inventory management and real-time data monitoring as per this study. The complexity of blockchain adoption was further examined and possible implementation issues including scalability, interaction with existing ERP systems, and privacy concerns are mentioned.

3.2. Viewpoints from other industries

Despite the fact that just a few studies were found focusing on aviation, many others not related with aviation industry provided interesting information that is also applicable to the management of aircraft spare parts. The knowledge of blockchain's potential uses is enhanced by those viewpoints from other industries. The use of smart contracts and blockchain technology to enhance existing predictive maintenance methods was studied by (Bagozi et al., 2019). The study illustrated blockchain's potential to decrease downtime of final products and improve products reliability. Multi-party collaboration is supported, by using blockchain to store sensor data and improve maintenance processes. These ideas are directly relevant to the aviation industry, in which efficient and proactive maintenance capabilities are necessary to reduce costs and reduce fleet downtime. As an example, airlines can perform scheduled maintenance before components/systems malfunctions occur by connecting blockchain with IoT devices to track the condition of vital components in real time. Blockchain methods proposed to reduce counterfeit parts in automotive industry supply chain were studied by (Meyliana et al., 2021). The study emphasized on using private blockchains to guarantee operational efficiency and ensure data security. Blockchain can provide a reliable framework for aviation supply chains, where compliance and traceability are of highly importance. By generating an unchangeable record containing immutable information regarding the utilization and the origin of spare parts. The researchers emphasized how blockchain's decentralized structure is able to minimize dependency on distributors. In addition, processes are simplified and fraud risks are mitigated. A blockchain-enabled 3D printing platform for spare parts management was introduced (S. Zhang et al., 2021). The users were able to gain from on-demand production, lower inventory levels. Traceability is improved through the mixture of blockchain technology with additive manufacturing. This method is also applicable to the aviation industry, especially during the manufacturing of aircraft parts. Blockchain may contribute to achieve compliance with safety procedures and regulatory compliance by guaranteeing the traceability of each 3D-printed part. "DestruChain," a blockchain-based system for handling the disposal of faulty spare parts in the automotive industry, was created by (Yuksel et al., 2021). Despite being centered on automotive applications, the method offers insightful information for aviation, particularly with regard to guaranteeing the safe and open disposal of non-conforming parts. By promising of proper disposal techniques, such a system can be adjusted for aviation use. It could satisfy regulatory requirements and promote environmental sustainability. Moreover, by focusing on effectiveness, enhanced traceability, and compliance, (Surjandari et al., 2021) investigated the application of permissioned blockchain networks for Halal supply chains. The concepts discussed, like smart contracts and multi-channel networks, are also applicable to aviation supply chains even if they are focused on a different industry and product. Similar technologies can be implemented in the aviation industry to increase supply chain confidence and increase stakeholder transparency. In order to enhance traceability in manufacturing supply chains, (Hasan et al., 2020) highlighted the integration of blockchain technology with decentralized storage systems such as IPFS. Their method offers data integrity and provides possible uses for aircraft spare parts. The study demonstrated how blockchain technology and off-chain storage can lower expenses without reducing data security. (Engelmann et al., 2018) investigated blockchain-based intellectual property protection in additive manufacturing. The aviation industry's emphasis on safeguarding designs and guaranteeing the legitimacy of 3D printed parts makes their findings also relevant. The aviation sector may promote innovation and improve regulatory compliance by managing licenses and traceability with smart contracts. With a focus on efficiency (Van Moergeste et al., 2018) looked into agent blockchain marketplaces for spare parts. This strategy fits with aviation's emphasis on supply chain traceability improvement and cost optimization. As per the experts, these marketplaces could help airlines acquire spare parts more efficiently, cutting prices and lead times. (Holland et al., 2018) investigated how blockchain can be used to manage digital rights and secure 3D printing procedures. The study emphasized how blockchain can stop illegal reproduction of critical components and emphasized the necessity for secure manufacturing settings in the aviation industry. The aviation sector, by utilizing blockchain technology into additive manufacturing processes can guarantee that approved and compatible parts are manufactured. Blockchain applications in mining and manufacturing were examined by (Jha et al., 2024), (Jha et al., 2023) with an emphasis on supply chain traceability. The management of aviation spare parts can benefit from their decisions on contract management, operational transparency and the mitigation of counterfeiting. The aviation sector may improve the resilience of its supply chain and adhere to global standards by implementing these methods.

3.3. Opportunities and Difficulties

There are various obstacles to overcome when incorporating blockchain technology into the administration of aviation spare parts. These include lack of regulatory clarity, high implementation costs, and compatibility with legacy ERP systems. Collaboration may be hampered by the reluctance of many stakeholders to provide sensitive information on decentralized platforms. Several research, including those (Cao et al., 2023) and (Aleshi et al., 2019), consistently identified these barriers. Notwithstanding these challenges, blockchain offers revolutionary possibilities. Real-time monitoring and predictive maintenance can be significantly improved by integrating blockchain with IoT and AI technology. Pilot projects that can show the advantages of blockchain use in aviation include those covered by (Richardo et al., 2022)and (Efthymiou et al., 2022). Also (Kabashkin, 2024) suggests the use of blockchain with digital twin technologies, to improve operational reliability by introducing new ways to lifecycle management and predictive maintenance. By solving multiple existing problems like counterfeit, compliance constraints and inefficiencies blockchain technology has the ability to drastically transform the management of aircraft spare parts. The research discussed in this chapter demonstrates how adaptable and scalable blockchain is in aviation-specific projects. The aviation industry can fully realize blockchain's potential and efficient supply chain operations by encouraging cooperation, regulatory alignment, and technology innovation. Ongoing research is important to continue and cooperation is emphasized by findings from multiple studies aviation-specific or even from other industries. To fully reap blockchain implementation benefits, more research and pilot projects are needed, making blockchain a vital component of contemporary airline logistics.

CHAPTER 4-Methodology And Application

4.1. Grounded Theory

Grounded theory is highly regarded for its ability to help qualitative researchers deeply explore social phenomena without prior assumptions, leading to richer theorization and a more nuanced understanding of contexts. We must mention that grounded theory faces criticism for several reasons. Managing the large volumes of data, the theory generates can be challenging, depending on the number of the interviews. Additionally, there are contentious debates around how to handle literature reviews and the concept of category saturation. The existence of multiple versions of grounded theory, while offering fresh perspectives and greater clarity, also introduces some confusion due to the lack of standardized protocols. These challenges contribute to the perception that grounded theory is daunting, costly and time-consuming (Dahwa, n.d.). On this chapter we provide a brief description of the different versions of grounded theory, as those are depicted in Table 4, and information is provided on the implementation method of the theory, on this thesis.

Table 4 Coding in Grounded Theory Projects

Glaser & Strauss (1967)	Comparing incidents applicable to each category
	Integrating categories and their properties
	Delimiting the theory

Glaser (1978)	Substantive coding (open coding followed by selective coding)
	Theoretical coding (using coding families)
Strauss & Corbin (1990, 1998)	Open coding
	Axial coding (using coding paradigm)
	Selective coding
Charmaz (2006, 2014)	Initial coding
	Focused coding
	Theoretical coding

4.2. Data Collection

As part of the data collection process the following actions have been carried out:

Questionnaire Development to facilitate the collection of qualitative data through open-ended questions that encourage the answerers to provide detailed responses. This data is essential for further analysis and implementation of grounded theory. Three main research questions are included, as per below:

- What are the primary challenges associated with traceability of aircraft spare parts, and how do these challenges impact the efficiency and safety in the aviation industry?
- To what extend do the SMEs in the aviation spare parts market understand and possess knowledge about blockchain technology, and what are the perceived benefit and barriers to its adoption?
- What potential challenges could hinder the implementation of blockchain technology in the aviation spare parts market, and what strategies could be developed to overcome these barriers?

Due to the type of the questionnaire, it is better to perform actual interviews to endorse detailed answers to be used as an input to grounded theory implementation. Interviews have been conducted with four (4) SMEs with extensive experience in aviation specializing in maintenance, SC and quality. All the interviews were recorded and transcribed to text documents. As it is derived through their interviews these individuals never involved in blockchain implementation projects especially related with aviation spare parts. In an effort to identify individuals with actual working experience in aviation sector and blockchain technologies LinkedIn platform was also utilized. Filtering including blockchain, aviation key words was used to filter LinkedIn user profiles and individual profiles were reviewed for selection. Following that a prompt message was sent to all the qualified individuals "*I hope this message finds you well. My name is Georgios Koutromanos, and I am a student in the postgraduate program "Supply Chain Management" at the Hellenic Open University. I am currently working on my thesis "Enhancing Aircraft Parts Traceability in the Aviation Supply Chain through Blockchain Technology: A Grounded Theory Approach" and I would appreciate your feedback on the questionnaire I have prepared. The questionnaire includes 13 open ended* *questions, and your insights would be invaluable in refining my research. In case you decide to participate, we could conduct a Microsoft Teams meeting to discuss the questions and provide your responses orally (preferred method), or I could forward to you the questionnaire to reply by an email. Thank you very much for considering my request. Your assistance is greatly appreciated".* It is emphasized that there was no response from any of the LinkedIn users. It is highlighted that the literature review will not be included in the grounded theory analysis. Instead, in Chapter 6, a comparison with the existing literature will be performed, highlighting similarities and differences. The questionnaire can be found in Appendix A of this dissertation.

4.3. Implementation of Grounded Theory

ChatGPT was used for grounded theory analysis which is capable to provide a structured approach to categorizing and analyzing data. The interviews were given as an input in pair with prompt questions and ChatGPT generated the results of the analysis. While ChatGPT offers significant support, it is essential to note that it shall be used as a tool. Researchers must interpret and validate the outputs, ensuring that findings are valid and grounded in the inputs provided. It serves as a mean of supporting grounded theory research by accelerating data analysis. When used appropriately as a supplemental tool, it complements the researcher's analytical skills, enabling more robust and efficient theory generation. No additional tools have been used as part of this qualitative analysis.

It is highlighted that grounded theory implementation can be introduced with different approaches. Traditionally known for its ability to produce theoretical insights from qualitative data, grounded theory also can be adapted when it comes to the review of literature. For example, in order to compile and examine the results of a bibliographic study of blockchain in supply chain management, this research(Rodrigues et al., 2023) utilized grounded theory. The authors identified important issues, traits, and outcomes related to blockchain adoption by using methodological phases such initial, focused, and axial coding. By using this method, they were able to provide a strong theoretical framework while bridging the epistemic divide between theoretical ideas and real-world applications. The applicability of grounded theory to literature review strengthens its value as a research approach. While it is often used to study real world data, like in our case for the interviews conducted with the subject matter experts, it can also be used to organize and understand earlier research. This use makes it a flexible method for exploring new ideas or confirming existing ones. By applying grounded theory to topics like supply chain and blockchain integration we gain a clearer understanding of complex issues.

CHAPTER 5-Analysis

5.1. Analysis Methodology

The analysis for this study was carried out using the grounded theory technique. Grounded theory is a qualitative research method that emphasizes in the creation of an hypotheses based on empirical data. This method was well-suited to examining the challenges and potential solutions for using blockchain technology in the aircraft spare parts industry. It allows for iterative data feedback and the emergence of themes that were not considered before. Referring to Table 5 Identified Concepts, the method began with open coding, where individual concepts were mined from the raw data from SME answers. These phrases, including "manual processes," "inconsistent documentation," and "financial obstacle," were directly raised from the language and ideas of SMEs. This step ensured that the analysis had a valid empirical basis. Axial coding was used to arrange related concepts into more generic groups following open coding. For instance, the labels "inconsistent documentation" and "manual processes" were positioned under the heading "Traceability Challenges." Referring to Table 6 Identified Categories, this stage provided a framework for understanding the data holistically and highlighted relationships between concepts. Finally, using selective coding, key categories that united the themes across the dataset were identified; see Table 7 Core Categories. Two core-basic categories, "Challenges in Blockchain Adoption" and "Solutions for Blockchain Adoption," were defined to produce topics that addressed the goals of the study. This repeated process ensured that the analysis was complete and reflected the actual data. The analysis revealed several gaps. For some specific themes, such as "supplier collaboration issues," further responses from SMEs may have improved the theory that was created. It was challenging to investigate various points of view due to the limited sample size. As an example, when we are talking regarding specialized subjects like scalability limitations and cross border regulatory issues.

Table 5 Identified Concepts

Concept	Description
Inconsistent documentation	Challenges in maintaining accurate part historical data
Manual Processes	Reliance on non-digital workflows for tracking parts
Financial Obstacles	High initial costs for implementing blockchain systems
Supplier Collaboration Issues	Limited participation of suppliers in blockchain systems
Integration Challenges	Difficulties in linking blockchain to existing ERP systems
Scalability Issues	Challenges in managing large datasets within blockchain frameworks
Lack of Training and Awareness	Gaps in knowledge about blockchain benefits among stakeholders
Regulatory Gaps	Lack of standards and policies supporting blockchain implementation
Cultural Resistance	Hesitation to adopt new technology
Data Security Concerns	Ensuring privacy and security of sensitive information on blockchain
Cost of Maintenance	Long term financial burdens of maintaining blockchain infrastructure
Resource Constraints	Limitations in staff or funding to support implementation
Standardization Needs	Lack of unified protocols for data entry and tracking in the supply chain
Stakeholder Collaboration Gaps	Challenges in engaging all stakeholders effectively
Complexity in Adoption	Perception of blockchain as a difficult technology to implement
Inventory Optimization Challenges	Difficulties in achieving efficient inventory management with current systems
Lifecycle Tracking Gaps	Issues in tracking parts across their entire lifecycle

Obsolescence Management	Managing outdated or expired parts effectively
Adoption Cost vs. Benefit Concerns	Balancing the cost of adoption against perceived benefits
Cross-Border Data Sharing Issues	Challenges in sharing data securely across international borders.
Pilot Project Requirements	Need for pilot projects to validate blockchain feasibility
Lack of Trust in Technology	Stakeholder second thoughts about blockchain's reliability and benefits
Long Implementation Timelines	Extended periods required to integrate blockchain systems effectively
Data Overload Risks	Potential issues with handling excessive amounts of data
Stakeholder Misalignment	Conflicting priorities and goals between stakeholders

Table 6 Identified Categories

Category	Description
Traceability Challenges	Issues related to inconsistent record-keeping and manual processes
Resistance to Change	Cultural and financial obstacles to adopting blockchain technology
System Integration Issues	Challenges in linking blockchain with existing systems and workflows
Supplier Collaboration Issues	Limited involvement of suppliers in blockchain ecosystems
Scalability and Performance	Concerns about managing data volume and performance in blockchain
Regulatory Challenges	Absence of clear standards and regulatory support for blockchain adoption

Table 7 Identified Core Categories

Core Category	Description
Challenges in Blockchain Adoption	A combination of obstacles including traceability status, resistance to change, and integration barriers.
Solutions for Blockchain Adoption	Strategies like pilot projects initiation, collaboration between stakeholders, and sufficient training.

5.2. Emerging Themes

Based on Table 8 Emerging Themes, three main problems surfaced from the research that capture the challenges, roadblocks, and viable fixes for blockchain acceptance in the airplane spare parts industry:

- **Implementing Blockchain Presents Difficulties** Aviation sector systemic inefficiencies make traceability challenging. Inconsistent record-keeping and a dependence on hand processes compromise parts lifetime tracking. Although blockchain being investigated as a solution for traceability problems, its application depends on reliable and consistent data from past systems. Furthermore, posing major technological challenges is the lack of interaction between blockchain systems and present ERP systems. Major stakeholders low embrace of blockchain technologies makes supplier interaction remain challenging. Organizational opposition to change aggravates these issues since many companies depend on old systems and are not ready to spend in new technologies.

- **Resistance to Change** Obstacle to Transformation Organizational and cultural resistance has been found as a main barrier to blockchain technology adoption. Many SMEs revealed the reluctance to give up proprietary systems that had been in use for years. Financial restrictions aggravate this antagonism, particularly for smaller companies with limited resources. Knowledge and training gaps are especially crucial since stakeholders usually lack the ability to grasp the possible benefits of blockchain. As a possible solution the need of exposure to experimental projects and additional training shall be provided to grasp the benefits of implanting blockchain and build up momentum.
- **Possible Adoption Solutions** nevertheless the difficulties, this study found a number of solutions to promote blockchain use. The benefits of the blockchain technologies in many aspects were multiple times proposed to be realized through pilot projects. Upon the establishment of standardized procedures and after encouraging resource sharing amongst industry stakeholders, including manufacturers, operators, and regulatory bodies the potential of blockchain can be effectively realized. Furthermore, focusing on long term economic benefits by utilizing this technology can encourage stakeholders to fund its deployment. Quantitative analysis of implementation results may lead organizations to earlier adoption.

Table 8 Emerging Themes

Theme	Description
Implementing Blockchain Present Difficulties	Identifies technical obstacles and systemic inefficiencies
Resistance to Change	Focusing on cultural, financial and awareness related barriers
Potential Solutions	Emphasizing in long term profitability and cooperative tactics to promote adoption

5.3. Observations and Gaps in the Analysis

Although the results are thorough, a number of observations and gaps surfaced throughout the study process. The majority of SMEs strongly agreed that pilot projects and industry cooperation are necessary, and they also agreed on the significance of transparency and traceability. It is highlighted that opinions on scalability and data volume problems differed, suggesting that more study on these subjects may be required to clarify and validate the findings. More SMEs, especially from smaller businesses or with more extensive blockchain knowledge could have helped to clarify specialized challenges like scalability and cross-border data management. Although SMEs saw the promise of blockchain, they also highlighted the need of additional testing and validation through pilot projects to reduce concerns about system performance in actual environments.

5.4. Constructed Theory

According to the grounded theory developed from this study, blockchain technology can improve transparency and efficiency of aviation supply chains particularly related with the aircraft spare parts. In general, blockchain has the potential to resolve significant traceability issues in the aviation spare parts sector. Systemic inefficiencies and cultural resistance which is part of human nature are acting as barriers to the implementation. Moreover, budgetary limitations, and regulatory deficiencies, stand as obstacles to its adoption and shall be addressed by provisioning of incentives to organizations and support from the authorities and regulatory bodies. In detail these obstacles can be addressed by taking planned steps, such as:

- Pilot Projects to show the viability and feasibility of blockchain.
- Industry-wide initiatives to create common protocols and make resource sharing easier
- Extensive training courses to raise consciousness and lessen resistance to change.
- Economical and scalable methods that allow smaller businesses to incorporate blockchain in a low budget.

5.5. Conclusion

The analysis chapter presents how blockchain technology has the potential to transform aviation supply traceability. However, to overcome difficult obstacles it will be necessary to realize this potential. Through pilot projects, setting of common goals and effective collaboration and focusing on long-term advantages, aviation might establish the framework for blockchain deployment. Future studies should concentrate on examining the legal modifications required to facilitate blockchain integration and confirming these tactics with a larger participant sample. SMEs are crucial in deciding on blockchain adoption methods, as seen by their strong consensus on topics like cooperation, transparency, and pilot projects. However, divergent views on scalability and regulatory limitations point to specific areas that require more focused future study. By taking these facts into account, the established theory resolves both well-known and particular issues, ensuring a just and useful foundation for blockchain implementation.

CHAPTER 6-Discussion

6.1. Overview of findings and comparison with literature

This chapter covers in great detail the analysis's findings as well as their relative merits to the body of knowledge existing in publication on blockchain technology and application in aviation supply chain management. The aim of matching the results with the research questions is to identify areas of agreement and disagreement with the existing literature. This chapter elaborates on the gaps between theoretical knowledge and practical insights gained during the study. The results of the study support several subjects covered in the literature on the advantages and challenges of introducing blockchain technology into the aviation supply chain. The key problem observed in the literature review contained in this thesis and in this study is the lack of a consistent and broadly accepted framework for blockchain deployment. As the literature review makes apparent, the aviation sector conducts business in multiple countries, each with its own regulatory framework and standards for part traceability, notably those established by the FAA and EASA. The findings of this investigation confirm the theory that lack of worldwide standardizing limits efforts to effectively apply blockchain technology. Regarding traceability, this study and the literature both highlight how transformative blockchain technology is in reducing paperwork errors, counterfeiting risks, and inefficiencies in general. The findings of this study line up with literature referring to blockchain's ability to offer immutable recordkeeping and real-time data sharing. As mentioned in Chapter 2, examination of counterfeit problems in aviation supply chains, stakeholders surveyed for this study also pointed out that blockchain's capacity to offer a single source of truth ought to reduce the likelihood of fake parts. These results support the widespread agreement in the literature that blockchain could greatly improve traceability and regulatory compliance. The literature underlines how blockchain can foster cooperation among supply chain stakeholders, by introducing a distributed data exchange platform. The results of the survey also show that SMEs have great hope for blockchain's ability to enable supplier, manufacturer, and MROs effective communication. The similarity of the above-mentioned findings emphasizes blockchain's potential as a transforming tool for aviation supply chain management. Although there are a lot of similarities between literature and the analysis' outcomes the results and the literature clearly diverge in certain important ways. One interesting issue is the impression of the price and complexity of blockchain implementation. The literature shows, as revealed by the example of blockchain application in aviation environments discussed in this thesis, modular and scalable blockchain solutions can lower high upfront costs and simplify acceptance. We need to mention that in other cases literature supports the fact that the initial implementation costs of blockchain technology are expected to be high. The study's participants, however, focused mostly on cost and complexity as main challenges; often, blockchain was seen as an impractical answer for smaller companies or those with limited resources. This discrepancy can arise from the industry's ignorance of successful case studies and sensible implementation strategies. Still another distinction is the degree of stakeholder readiness for blockchain acceptance. Although the research indicates that individuals are growing more conscious of the benefits of blockchain, this study reveals that stakeholders, particularly in the aviation industry, lack practical expertise a fact both the interviewees and this thesis both acknowledge. Though they had theoretical knowledge, the professionals under interview were not exposed to actual use cases or implementation practices. This study reveals a discrepancy between theoretical understanding and actual preparedness that the literature now under publication does not sufficiently handle. Since this study did not employ repeated interviews to obtain theoretical saturation, its research approach deviates even more from best standards stated in grounded theory literature. While looking at developing themes was the primary objective, the absence of iterative data collecting could have narrowed the depth of results than in studies using more comprehensive methods. This methodological deviation highlights the need of iterative approaches to theoretical construct improvement for future research. Building on the results of the literature review in Chapter 3, this study adds new perspectives to the discussion of blockchain adoption in the aviation supply chain. The unique difficulty of integrating blockchain technology with current enterprise resource planning (ERP) systems is one emerging theme. Although interoperability problems are acknowledged in the literature, the results of this study show how much legacy systems and decentralized blockchain platforms can conflict, posing serious technological obstacles. This realization emphasizes the necessity of customized solutions that give compatibility with current infrastructure first priority. This study also reveals complex regulatory issues, especially the rules that are enforced by several aviation authorities and can overlap and clash. Respondents voiced worries that blockchain deployments would unintentionally make compliance procedures more difficult rather than easier. This research highlights the significance of cooperation between regulators, business executives, and technology suppliers and implies that regulatory alignment is a necessary precondition for the effective implementation of blockchain. The focus on blockchain applications unique to the aviation industry, such real-time part monitoring in emergency maintenance situations, is another noteworthy contribution. These aviation-specific insights offer a greater grasp of the technology's utility in high-stakes operational contexts, as investigated in the analytical portion of this thesis, even if the literature covers blockchain applications in supply chain management in general. These results point to areas where more research can be done to examine specific blockchain solutions that are suited to the particular requirements of the aviation sector.

This study’s findings provide valuable insights into the three primary research questions:

1. Challenges associated with traceability: The study confirms that the aviation industry faces significant challenges in ensuring parts traceability, including counterfeiting risks, inefficiencies, and documentation errors. Blockchain technology is capable to address these issues by providing immutable records and real-time data sharing, as supported by both the literature and stakeholder perspectives.

2. Blockchain awareness and perceived benefits: While stakeholders demonstrate theoretical knowledge of blockchain’s potential, their lack of practical experience highlights a readiness gap. This finding aligns with the literature’s emphasis on the need for education and pilot projects to bridge this gap.

3. Barriers to implementation: Cost, complexity, and regulatory alignment emerged as key barriers to blockchain adoption. These challenges are in agreement with the literature, but this study’s focus on aviation-specific contexts, such as legacy system integration, adds depth to the understanding of these barriers.

In conclusion, this chapter has synthesized the findings of this research with existing literature, identifying areas of alignment, divergence, and new insights. The study reinforces the potential of blockchain technology to address traceability challenges in the aviation supply chain while highlighting practical barriers and opportunities for targeted interventions. By bridging the gap between theoretical knowledge and practical application, this research contributes to a deeper understanding of how blockchain can transform aviation supply chain management. Future research should build on these insights to explore scalable solutions which are interoperable, and aviation-customized to meet the stakeholders’ expectations.

6.2. Practical Implications

The study's conclusions have a number of real-world ramifications for industry participants. First, given the promising impression of blockchain's traceability advantages, aviation companies ought to give priority to pilot projects in order to confirm its effectiveness. Blockchain's ability to increase supply chain transparency and decrease operational inefficiencies can be illustrated through initiatives such as blockchain-enabled platforms. Second, industry cooperation is needed to create scalable, user-friendly blockchain solutions in order to overcome the cost and complexity obstacles found in this study. Technology suppliers and vendors need to concentrate on developing flexible systems that meet the various requirements of small, medium, and big aviation companies. Programs for education and training are also necessary to close the knowledge gap between theory and practice, empowering stakeholders to make well-informed choices regarding the implementation of blockchain. Third, the study's integration issues need the creation of interoperability standards, a topic covered in-depth in this thesis, to enable smooth communication between blockchain platforms and legacy ERP systems. In order to guarantee that blockchain implementations support compliance efforts rather than impede them, regulatory agencies and industry consortia should collaborate to create frameworks that encourage compatibility.

6.3. Limitations and future research

While this study provides valuable insights into the potential of blockchain technology for enhancing traceability in the aviation supply chain, certain limitations must be acknowledged. A significant constraint was the limited prior experience of interviewees with blockchain applications in the aviation industry. Although most stakeholders expressed a positive outlook on the technology's potential, their perspectives were theoretical and lacked practical exposure to implementation challenges and complexities. Additionally, the number of interviewed stakeholders was limited, which falls short of the recommended minimum for grounded theory research. This limitation may affect the generalizability of the findings. Furthermore, no iterative interviews were conducted, as the primary objective was to explore the application of grounded theory rather than achieving theoretical saturation. Future research could address these limitations by involving a broader range of industry experts with hands-on blockchain experience and conducting multiple interview rounds to refine emerging themes and theoretical constructs. Research could also focus on developing frameworks for the seamless integration of blockchain with legacy systems and regulatory standards. The theoretical framework created in this study could be further improved by longitudinal research and iterative interviews. Pilot projects assessing blockchain's viability in diverse aviation situations would offer useful insights into the advantages and difficulties of its adoption. These initiatives ought to concentrate on evaluating regulatory compliance in cross-border situations, investigating scalable solutions, and integrating blockchain with older systems. Research might also examine the financial implications of blockchain adoption, weighing cost-benefit ratios and investigating financing options to assist small and medium-sized aviation businesses. Lastly, investigating how blockchain interacts with cutting-edge technology like digital twins and artificial intelligence may reveal novel uses for aviation part lifecycle management and predictive maintenance.

CHAPTER 7-Conclusions

This chapter outlines the research's findings, summarizes its contributions to knowledge, and provides a thoughtful analysis of the study's importance. It goes on to outline the findings' ramifications for the aviation sector, highlighting a blockchain's revolutionary potential in supply chain management. The chapter also discusses viewpoints that haven't been covered extensively before and offers suggestions for further research. The application of blockchain technology to enhance traceability in the aviation supply chain, was carefully examined as part of the study. Important traceability issues, such as manual procedures, inconsistent documentation, and issues with cross-border data sharing, were identified by the study using a grounded theory approach. Blockchain has emerged as a potential solution to these issues due to its capacity to offer immutable record-keeping, real-time data interchange, and enhanced supply chain transparency. According to the study, blockchain can reduce risks related with counterfeiting and increase stakeholder trust by creating a single source of truth. It also demonstrated that subject matter experts had high hopes for blockchain's capacity to improve communication between manufacturers, suppliers, and maintenance firms. However, adoption barriers were found to be significant and included uneven laws, high implementation costs, and challenges interfacing with legacy ERP systems. This paper adds much to the fields of supply chain management in aviation and blockchain. The study adds to our knowledge of how blockchain can improve traceability and how it might help address issues specific to aviation supply chains. The study shows how to explore complicated, industry-specific phenomena by employing grounded theory. A data-driven investigation of the application of blockchain is ensured through structured interviews with subject matter experts. The results give aviation stakeholders practical advice on how to prioritize pilot projects, create regulatory frameworks, and encourage industry cooperation. Along with the main conclusions, this study offers fresh viewpoints that weren't thoroughly discussed in earlier chapters. In addition to education and legislative harmonization, it is essential to incentivize stakeholders to embrace blockchain. Tax breaks for early adopters or financial assistance for SMEs to test blockchain initiatives are two possible approaches. Sustainability objectives are in line with blockchain's promise to save waste and simplify inventory management. Better part lifetime tracking, for instance, helps reduce overproduction and guarantee that outdated components are disposed of properly. Proactive supply chain decision-making and predictive maintenance are made possible by integrating blockchain with other technologies like IoT and AI. Innovation in the aviation industry may be stimulated by these intersections. To sum up, this study demonstrates how blockchain technology has the potential to completely transform aviation supply chain traceability. Blockchain provides a route to safer, more transparent, and more effective supply chain operations by tackling important issues including counterfeit dangers, inconsistent documentation, and inefficiencies. But in order to achieve this potential, major obstacles must be removed, such as excessive implementation costs, misaligned regulations, and change-averseness. By offering both theoretical insights and useful suggestions, the study adds to the expanding body of knowledge on blockchain's uses in supply chain management. The findings set the stage for further developments in this area by highlighting cooperation, regulatory harmonization, and education. As blockchain technology develops further, its application to aviation supply chains has the potential to revolutionize the sector by guaranteeing improved operational excellence, safety, and compliance.

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Appendix A

INTERVIEW QUESTIONNAIRE

THESIS TITLE

Enhancing Aircraft Parts Traceability in the Aviation Supply Chain through Blockchain Technology: A Grounded Theory Approach

Georgios Koutromanos

Thesis Summary

This Thesis investigates the challenges of aircraft parts traceability in the aviation SC and explores the potential benefits of blockchain technology's implementation. Grounded in empirical data collected from subject matter experts (SMEs), grounded theory methodology is being used to develop a substantive theoretical framework. The research contributes to the understanding of how blockchain can address existing issues and improve safety, compliance and efficiency in aircraft maintenance and SCM.

Questionnaire Purpose

The purpose of this questionnaire is to facilitate data collection in a systematic and structured manner while also allowing for flexibility and exploration of emergent themes. The questionnaire facilitates the collection of qualitative data through open-ended questions that encourage the respondents to provide detailed responses. This data is essential for further analysis and identification of key themes and patterns. The questionnaire is structured in way to accumulate data regarding the three main research questions, which are the following:

- What are the primary challenges associated with traceability of aircraft spare parts, and how do these challenges impact the efficiency and safety in the aviation industry?
- To what extent do the SMEs in the aviation spare parts market understand and possess knowledge about blockchain technology, and what are the perceived benefits and barriers to its adoption?
- What potential challenges could hinder the implementation of blockchain technology in the aviation spare parts market, and what strategies could be developed to overcome these barriers?

Interview Recording

As part of this research, interviews will be conducted with relevant stakeholders from the aviation value chain. It is important to note that these interviews will be recorded for accuracy and completeness of data collection purposes. The recordings will be used solely for research analysis and will be treated with utmost confidentiality. Stakeholder's identities will be kept anonymous in any publications or reports resulting from the study.

Insights on Blockchain Technology

Blockchain is a distributed transactional data structure that stores records and information managed by the consensus mechanism and secured by cryptography. Distributed ledger technology (DLT) forms the basic design framework for many blockchain-based systems. The data records are called blocks and distributed ledgers are called chains. Numerous blocks and chains are connected to create a blockchain computer network and the ledger transactions are processed and verified by the cryptography autonomously. A completed blockchain system can be classified as public (no permission required) or private (permission required). Bitcoin was the first public blockchain system, adopted the proof of work (PoW) consensus mechanism. In detail PoW is a protocol for proving verification under particular computational effort within a time interval by forcing computers to compute. PoW enhances blockchain security and assures the transactions are processed promptly, which is beneficial for public blockchains due to the high number of participants. A key benefit of using the distributed system is that no single entry controls the operation, therefore accountability and disclosure between individuals are the outputs. Important data can be updated in real time, minimizing the labor and error of individual internal data reconciliation and providing to the participants close monitoring of the actions inside the network. Furthermore, the blockchain data is immutable, which means the transactions already performed cannot be altered or deleted. [1]

Queries

1. What specific challenges do aviation industry stakeholders encounter in tracking the origin and lifecycle of aircraft spare parts?

2. What risks arise from the use of different systems and technologies for tracking and managing spare parts data?

3. How do issues such as incomplete or inconsistent record-keeping impact the traceability of aircraft spare parts?

4. Are there regulatory or compliance-related challenges that affect the traceability of aircraft spare parts, such as documentation requirements or certification standards? And how you comply with those?

5. Are there challenges related to data integrity, accuracy that act as an obstacle to effective traceability of aircraft spare parts?

6. What is the level of your familiarity with the basic concepts and principles of blockchain technology? Are you aware of any specific blockchain platforms that have been developed for the aviation industry?

7. How do you visualize the potential benefits of blockchain technology for enhancing traceability and transparency in the aviation spare parts market?

8. What are your thoughts regarding the capabilities and limitations of blockchain technology?

9. Are there cultural or organization barriers within the industry that may hinder the adoption of blockchain technology?

10. Can industry-wide collaboration, standards development and authorities support facilitate adoption and implementation of blockchain technology for enhancing traceability and safety?

11. How do perceptions of risk impact stakeholders’ will to invest in blockchain solutions for aircraft spare parts traceability?

12. Do you believe it would be challenging to implement in your organizations’ sourcing criteria as a mandatory requirement to approve suppliers of spare parts, implementation of blockchain technology?

13. In your opinion, what are the implications of the initial investment expenses required for the implementation of blockchain technology? Do you believe these financial considerations might pose obstacles to the adoption of blockchain in the future?

Questionnaire References

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