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An Exploratory Research on Blockchain in Aviation: The Case of Maintenance, Repair and Overhaul (MRO) Organizations

Marina Efthymiou [1,*], Katie McCarthy [1], Chris Markou [2] and John F. O'Connell [3]

[1] Dublin City University Business School, University of Dublin, D09 Dublin, Ireland; katie.mccarthy24@mail.dcu.ie
[2] International Air Transport Association, 800 Rue du Square-Victoria, Montréal, QC H4Z 1M1, Canada; markouc@iata.org
[3] Centre for Aviation Research, School of Hospitality and Tourism Management, University of Surrey, Guildford GU2 7XH, Surrey, UK; frankie.oconnell@surrey.ac.uk
* Correspondence: marina.efthymiou@dcu.ie

Abstract: The aircraft maintenance sector has high complexity with many intermediaries, multiple actors sharing data and needs to ensure high data security. The implementation of Blockchain technology can significantly contribute to the aforementioned characteristics. This research explores the implementation of Blockchain technology in Maintenance, Repair and Overhaul (MRO). For this research, a mixed-method approach was followed to obtain a holistic view of the adoption of Blockchain technology in an aircraft maintenance facility. Semi-structured interviews and a case study were used. The interview findings related to the current status of maintenance records management. The findings also highlighted the value of data storage within MRO's and the benefits of Blockchain. The paper also discusses the readiness/willingness of aircraft maintenance facilities to implement Blockchain and the barriers to implementation. Recommendations and areas for further research are identified.

Keywords: blockchain; maintenance; repair and overhaul (MRO) organizations; technology implementation; smart contracts; data sharing

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1. Introduction

Maintenance, Repair and Overhaul (MRO) is complex, as various regulatory policies, varied customer portfolios, heavy reliance on parts supply chains, human reliance and tight time schedules make it challenging to capture and manage information effectively. is becoming an increasingly urgent requirement in supply chains, and the lack of transparency prevents the verification of the actual value of items and can cause strategic and reputational competitive issues [1]. Similarly, the need to trace and verify parts in maintenance is of significant importance for MRO, with strict requirements outlined by airworthiness authorities to guarantee the safety of aircrew and passengers [2]. The maintenance sector has high complexity with many intermediaries, multiple actors sharing data and needs to ensure high data security. Vastly improved data storage and communication technology is a major opportunity for improving aviation's performance [3]. Moreover, counterfeit products within the aircraft parts supply chain compromise safety standards. The implementation of Blockchain technology can significantly contribute to the characteristics mentioned above and can assist with the elimination of any counterfeit products within the aircraft parts supply that compromise safety standards.

Blockchain technology is claimed to be one of the most influential and innovative technologies currently [4]. Blockchain can be described as a distributed ledger, a chain of 'blocks' in chronological order where each block has a record of the activities that have taken place on the network since the last block was added to the chain [5]. Efficiency gains enabled by Blockchain could increase industry revenue by as much as 4%, or US$40bn, while cutting MRO costs by approximately 5%, or US$3.5bn [6].

Some studies have reported the benefits of Blockchain (e.g., [7–10]). Some research has been conducted in aviation. For example, [11] examined Blockchain for flight data sharing in air traffic control; [12] looked at Blockchain in Controller Pilot Data Link Communication (CPDLC) from a technical perspective but did not evaluate its adoption willingness. Ref [13] used a prototype of a permissioned Blockchain for the maintenance documentation of aircraft and their components and explained how this could be used. looked at building digital twins in additive manufacturing in aircraft using Blockchain. Several piloting programs across various sectors have been trialed, but the technology penetration levels for Blockchain remain minimal [14].

Research into Blockchain is at an early stage in terms of theoretical grounding, methodological diversity and empirically grounded work [15]. With most of the research being undertaken on the benefits of Blockchain and the use cases, conducting more research on organizational practices and decision-making around the adoption of Blockchain technologies [15]. Blockchain can be a disruptive technology for design, organization, operations and general management [1]. Therefore, the resistance to implementing Blockchain needs to be further explored.

This research aims to explore the adoption willingness of Blockchain technology in Maintenance, Repair and Overhaul (MRO). Despite the aforementioned academic and industry interest, our understanding of Blockchain technology's adoption and implementation issues remains limited [16]; hence, this research will contribute to a better understanding of why. More specifically, organizational readiness is the least explored area [17] and needs to be evaluated. Through this research, we expect to gain insight into the following:

- The existing application of Blockchain and how this can be adapted to be implemented in aircraft maintenance facilities;
- The characteristics and benefits of Blockchain technology;
- The willingness of aircraft maintenance facilities to implement Blockchain and the barriers for implementing Blockchain within MRO.

Section 2 outlines the fundamentals of Blockchain, focusing on the advantages and criticism of the new technology and the MRO industry needs. Section 3 outlines the research method followed, i.e., the use of Dublin Aerospace as a case study and the interviews with key MRO and Blockchain experts. The analysis of the study results is presented in Section 4. Finally, Section 5 concludes the research, discusses its implications for academic and aviation practice and considers the study's limitations related to further research.

2. Literature Review

2.1. Blockchain Technology

Blockchain is a digitally distributed transaction ledger in that information is stored and maintained (but not duplicated) on a decentralized database, which belongs to multiple entities sharing information [5]. Distributed ledgers are ideal when the supply chains are large and complex, such as in aircraft maintenance, as it ensures high security and safety, and there can be multiple organizations involved. Blockchain is a continually growing list of records called blocks that are permanently linked to a chain. Within MROs, data could be inputted manually into a Blockchain by authorized staff or automatically by maintenance management systems. According to Blockchain rules, once data is entered into the system, it is shared with all participants on the Blockchain, and that block of data entered cannot be altered.

If implemented in MROs, the aftermarket blocks would contain data on aircraft parts, such as (1) Where they came from, (2) Which airline operated them, (3) How many hours were they operated for, (4) When and what failed, and (5) Who, when and where they were repaired. This is commonly known as Back-to-Birth traceability (or BtB). Blockchain uses cryptography instead of signatures to ensure security. In the MRO industry, it would only collect the maintenance data necessary for safe transfers and, in the case of a private Blockchain, transferring sensitive data [18].

Currently, Blockchain systems can be categorized into three groups, private, public and consortium Blockchain. The primary distinction between private and public Blockchain is who can participate in the network [19]. Public and private Blockchains can also be classified as permissionless and permissioned, respectively. Permissionless refers to a situation in which anyone can join and participate in the network. Anybody can create a personal address and interact on the network by adding entries to the ledger and submitting transactions. The public or permissionless Blockchain network is used in most digital currencies worldwide [20]. Consortium Blockchain is only publicly available to a selected few parties. The consensus process is active and controlled by a public party that sets the rules and guidelines for the Blockchain. It is only partly decentralized, as the Blockchain copies are only distributed amongst certain entities.

The main characteristics of Blockchain are (a) Digital Signatures, (b) Data Integrity, (c) Smart Contracts, (d) Alternative consensus algorithms, (e) Proof-of-Work and (f) Peer to Peer. The individuals on the network use digital signatures in Blockchain to ensure that the new blocks created are legitimate and authentic. Digital signatures are an extra layer of security. The use of hashing algorithms guarantees integrity [21]. Encrypted data being sent can be altered without being detected by a hacker. If the data were hacked, the signature would change; thus, it would be invalid. They secure the data and the identity of the individual creating it. Ownership of digital signatures is bound to a user and the individuals they intend to share it with. Nevertheless, a signature is auditable and verifiable, so the owner cannot deny its existence.

Data integrity is a fundamental component of information security and safety. It is achieved in Blockchain with hashing; hashing can confirm that it has not been tampered with [22]. Each block within the Blockchain produces a hash value into a digest; the digest publishes the proof that the data in the block is secure and its integrity remains [5]. Blockchain is immutable and allows for confidence in the quality of data. Blockchain plays a significant role in avoiding fraudulent transactions [15]. Cryptography and its decentralized nature make Blockchain impossible to modify data or hack the system.

The smart contract, also known as a cyptrocontract, can be programmed electronically and automatically enforces itself when the conditions determined in advance are met [23]. The fundamental objective of a smart contract is to reduce transactional costs while providing superior security. Given the complex nature of the aviation industry value chain, smart contracts can enable an efficient flow of transactions between these different entities. Proof-of-work (PoW) is used to verify the legitimacy of data; this system can be implemented to provide a consensus within the network.

Trust is one of the essential elements in Blockchain [15]. Blockchain technology is open-ended; it operates on a decentralized basis, allowing data to be stored and exchanged on a peer-to-peer (P2P) basis. P2P will enable individuals who do not know or have a relationship with others to form a trustworthy ledger where information is stored. This information can consist of contract outlines, payment history and data [24] and is tamperproof, making Blockchain transparent. Allowing direct access to several information systems instead of one system generates higher efficiency [15] and faster execution [25]. P2P systems have been researched and identified as a system that can be used in several areas concerning exchanging and storing data [26,27].

Blockchain data can be shared and secured due to consensus-based algorithms. The consensus mechanism is a program where nodes agree on a result; each participant's system validates the information and distributes it to the other participants. When each participant has received this information, each computer system runs the same algorithms to achieve the correct result [28].

In conclusion, Blockchains' main characteristics are (a) efficient transaction settlement, (b) transparency and auditability and (c) reliability [29]. Nevertheless, Blockchain technology implementation requires a significant financial investment, which is a challenge for many organizations [15,30]. Barriers can be grouped to intra-organizational, inter-organizational, system-related and external barriers [1]. The barriers relevant to MROs are a hesitation to share information, limited use cases in MRO and technical challenges. According to Gartner's Blockchain spectrum model, Blockchain technology is growing, and Blockchain-inspired solutions will dominate enterprise implementation in the early 2020s. In 2023, enterprise-ready complete solutions will emerge, and in 2025 Blockchain will incorporate complementary technologies (e.g., Internet of Things and artificial intelligence).

2.2. Technology Adoption

The three clusters in general management and economics related to Blockchain are law, economy and innovation [30]. The law papers look at intellectual property (IP), copyrights, e-residency and data protection. The economy papers discuss financial services, initial coin offerings (ICO), risk, cryptocurrencies and the sharing economy, while the innovation cluster researches a broader spectrum of topics. There are various theories applied to Blockchain, ranging from transaction costs [1,31], to disruptive innovation theory [16], to social capital and exchange theory [1], to network theory and principal-agent theory [32] and to technology readiness and acceptance [33].

Technology adoption is a complex developmental process that individuals influence, constructing unique (but malleable) perceptions of technology [34]. Adoption theory examines the individual and the choices the individual makes when accepting or rejecting a particular innovation. The most popular theories and models of technology acceptance are the Theory of Reasoned Action, the Theory of Planned Behavior, the Theory of Interpersonal Behavior, the Technology Acceptance Model, Social Cognitive Theory and Diffusion of Innovations Theory [35]. Innovation diffusion theory, developed by Rogers, is related to technology adoption theory. This theory explains how innovation is communicated through certain channels over time among the members of a social system. In contrast, technology readiness refers to people's propensity to embrace and use new technologies for accomplishing goals in home life and at work [36].

The literature on Blockchain adoption is highly diverse [37]. They argue that Blockchain in technology adoption lies within the theoretical foundations listed in Table 1. Similarly to [37], we have based our research on the listed theories and expanded on the decision-making in technology adoption. There are five decision-making stages [38]. In the case of Blockchain, firstly, an individual needs to become aware of the existence of Blockchain as an innovative technology. In the second stage of persuasion, the individual gains enough knowledge about Blockchain characteristics (outlined in Section 2.1) to make a personal judgment of the technology's value. Stage three is when the individual takes a decision, and stage four is the implementation of the decision. Finally, at stage five, the individual reflects on the decision and implementation process and re-evaluates whether to continue or discontinue the technology adoption. Cognitive, emotional and contextual concerns need to be addressed to enhance technology adoption [34].

Relative advantage, trialability, compatibility, complexity and observability influence technology adoption [38]. Relative advantage is the degree to which innovation is perceived as being better than the idea it supersedes [39]. In the case of Blockchain, the numerous benefits of Blockchain strengthen the relative advantage of the technology. Moreover, perceived usefulness plays an integral part and, according to technology adoption literature, is more important than perceived ease of use [40].

Table 1. Theoretical foundations of Blockchain technology adoption [37].

Theories	Relevance for Blockchain Adoption	Limitation for Blockchain Adoption
Diffusion of Innovation	• The decision of an individual or organization to make use of an innovation • Diffusion as the accumulated level of users of innovation in a market • Relevant tool to understand the benefits of Blockchain technology • Relevant for the assessment of Blockchain adoption and diffusion complexity • Role of early adopters in defining the success of adoption	• Has limited applicability for technologies with network externalities/network effects • The assumption that rational adopters are free and independent to choose to adopt or not to adopt an innovation • Neglects environmental context
Technology–organization–environment	• Organizational level • Role of the external environment • Impact on the adoption decision • Classifies the challenges and benefits of adoption	• Missing critically important variables such as uncertainty • Neglects mimetic, coercive and normative institutional pressures towards IT systems • Neglects the role of individual characteristics (e.g., top management support)
Network externalities	• Network externalities: adopters care about how many users adopt Blockchain • Market power externalities: adopters with market power will care about adoption by others if early adoption of Blockchain implies some market power • Learning externalities: early adopters of Blockchain may teach late adopters something useful	• Neglects the characteristics of the market, organization and technical changes
Adoption under uncertainty	• Market uncertainty: affects the investment and the delay of the adoption • Technological uncertainty: expectations about the timing of future and continuous improvements may lead to postponing the adoption and diffusion of Blockchain	• Adoption is driven mainly by euphoria in anticipation of short-term gains and a pervasive fear of missing out, neglecting other factors.
Institutional isomorphism	• Adoption of Blockchain-based on mimetic/peer pressure: institutional pressures from the environment will magnify the homogeneity of practices across organizations and increase the adoption • Isomorphic/mimetic pressures are particularly acute under conditions of high ambiguity and technological uncertainty	• Adoption is based mainly on myths in the institutional environment rather than a calculus of costs and benefits

2.3. Maintenance Repair and Overhaul: The Industry Needs

MROs are described as when "all actions that have the objective of retaining and restoring an item in or to a state in which it can perform its required function. The actions include a combination of all technical and corresponding administrative, managerial and supervision actions" [41]. Aircraft maintenance is essential to guarantee the safety and security of the aircraft in commercial airlines [2]. An aircraft fleet is one of the airlines most valuable assets. Maintaining the fleet plays a crucial role in ensuring the reliability and safety of these fleets in the commercial and private sectors [42]. MRO is seen as a significant percentage of airline operating costs; it represents approximately 12–15% of airline costs annually. There are over 480,000 people directly employed in MRO worldwide, and annual expenditures on MRO were estimated to be approximately $50 billion in 2013 [2] and over $80 billion in 2019.

Aircraft maintenance can be categorized into scheduled and unscheduled maintenance. Scheduled maintenance ensures that products function correctly at pre-set times; these are routine inspections, with 'A', 'B', 'C' and 'D' checks broken down into line maintenance (the aircraft remains under the control of Operations) and base maintenance (the aircraft is removed from service and usually-placed in a hangar for a few days, at least) categories. They are preventative actions. Unscheduled maintenance is not pre-planned [43]. The maintenance of each part of an aircraft must be continuously tracked throughout its lifecycle, with the maintenance of documentation and originality/quality being an essential task for MROs. For example, a Boeing 737 has 367,000 parts, and keeping accurate aircraft maintenance records of these parts is critical in proving an aircraft's airworthiness. The supply chain in the aviation industry is highly complex (as seen in Figure 1). Once an aircraft begins operations, its parts become part of a global supply chain involving several parties, such as Original Equipment Manufacturers (OEMs), lessors, airlines, MROs, regulators and parts manufacturers. Each party has its system for storing data and information about parts and aircraft in its possession.

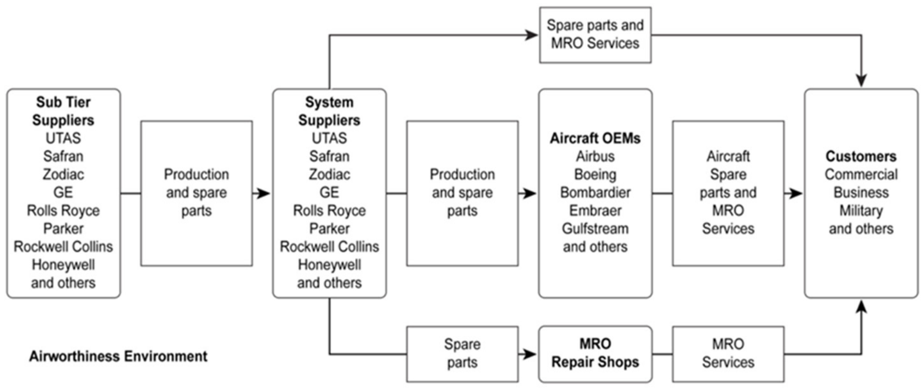

Figure 1. Simplified parts and MRO services flow in the aeronautical industry (Source: Vieira and Loures, 2016).

When an aircraft or a part of an aircraft is transferred, there is complex paperwork to ensure authenticity. The paperwork includes physical paper tags and an extensive history about the part or aircraft, with a record of all repairs and modifications that have taken place. The part leaves the Enterprise Resource Planning (ERP) of the MRO and is transferred to the ERP of the airline. Then, the cycle repeats itself, this time possibly with a different MRO. If the part is crossing international borders, the customs office becomes involved. Reports must also be carried out to ensure airworthiness and commercial traceability. Each year, millions of parts are moved worldwide; this can lead to a high level of inefficiency and lack of transparency, leading to added costs. The decentralized identifier (DID), a unique, verifiable, decentralized digital identity, can be the mechanism to trace the full records of a part.

At present, aircraft maintenance logbooks are stored in a physical ledger, typically in the aircraft and/or in the aircraft's owner's possession. Several risks are associated with maintaining a physical logbook; for example, it is susceptible to being damaged and lost or stolen, rendering the aircraft not airworthy. If the aircraft logbook is mislaid, the records must be reconstructed, leading to delays and increased costs. In addition to this, the reconstruction of maintenance logs can be a long and tedious task. As each aircraft ages, the maintenance facility that carried out work may no longer be in business, and therefore they may not hold the records for this aircraft. If this is the case, the aircraft owner must make a notarized statement explaining the loss of records and estimate the time the aircraft was in use according to the Federal Aviation Administration [44]. Finally, it is possible to falsify records through the forgery of signatures with physical logbooks.

Paper records account for nearly 90% of all commercial aircraft maintenance records worldwide. An aircraft will typically be owned by five or six owners between delivery and retirement. Maintaining documentation is a challenge due to the high volume of movement and activity throughout the aircraft's lifespan. Maintenance records for legacy aircraft are vulnerable to damage, missing documents and even misinterpreted handwritten text. Considering the number of documents, it is probable that the history of the maintenance of an aircraft will not be complete.

Digitally transferring data can create problems: the buyer and seller may be using different systems that are not compatible, and therefore there is a risk of data being lost. Thus, the interoperability of Air Transport Association (ATA) standards and the security of transferring data become paramount when electronic data transfers occur.

The second most important problem for MROs is the use of spare parts. Individual aircraft parts and airframes are imported, the inventory is maintained and the aircraft is assembled. The aircraft supply chain is well regulated and monitored at individual levels. There is the risk that replacement parts may be unapproved or of substandard quality replication or products sold on the black market. Counterfeiting strategies are evolving and becoming more sophisticated and are increasingly affecting the legitimacy of the supply chain; this applies to things such as stolen or parts recovered after they have been permanently removed from service. Parts are manufactured illegally by sub-contractors and then sold as legitimate parts [45].

The aviation industry's number one priority is safety, and it is deeply concerned with detecting counterfeit products within the aircraft parts supply chain [13,46]. A small number of aircraft parts may be counterfeit or missing records, which can have a detrimental result if they are not manufactured to the standards set by regulators. In 2016, the FAA stated that 273 counterfeit parts from China were installed in some Boeing 777 wing spoilers—these caused the aircraft to slow down during landing [47]. If Blockchain technology was implemented in MRO, a common ledger would be used by all relevant parties for entering, storing and retrieving information regarding the aircraft and its parts.

3. Methodology

Exploratory research is frequently conducted in aviation [48,49]. This explorative research investigates the implementation of Blockchain technology in aircraft maintenance facilities. For this practice-oriented research, a mixed-method approach was followed to obtain a holistic view of the implementation of Blockchain technology in an aircraft maintenance facility. A case study and semi-structured interviews with senior experts were used.

A case study is described as a research strategy that is an empirical inquiry to examine a subject matter within a real-life context [50] and captures experiential understanding [51]. Various scholars have used case studies in aviation [49,52–54]. Research by case studies is a valuable research strategy when the topic is broad and complex, when the theory is limited and when the context is crucial [51,55–57]. These three conditions apply to this research. Thus, a single case study conducted from a realist standpoint was used to understand the process of maintenance verification and records management in MRO.

Dublin Aerospace was selected as a representative MRO that can reflect the processes of maintenance verification and records management followed by other MROs to allow a situated generalization. Dublin Aerospace is based at Dublin International Airport, Ireland. The facility is 20,000sqm and covers hangars 1, 4 and 5. Currently, Dublin Aerospace provides maintenance and repair services (base maintenance, landing gear overhaul and Auxiliary Power Unit (APU) repair and overhaul) to the aviation industry. Building on a foundation of over 50 years of experience in the Aerospace industry, Dublin Aerospace is one of the world's leading providers of aerospace MRO services. They currently hold approvals from several worldwide authorities, including the European Aviation Safety Agency (EASA), the Federal Aviation Administration (FAA) and the Irish Aviation Authority (IAA), and are based at Dublin Airport. Dublin Aerospace focuses primarily on Airbus A320 and Boeing B737 Base maintenance (all levels of C checks), Landing Gear repair and overhaul and the repair and overhaul of Honeywell type APU's. They have four narrow-body Hangar bays at Dublin airport and operate a base maintenance facility that can presently handle approximately 70 aircraft per year. It also has an APU overhaul center that can handle 400 APUs per year and a Landing Gear service center that has the capacity for 250 legs per year. Apart from providing services to airlines, Dublin Aerospace also offers services to Aircraft Leasing companies during lease transitions and hand backs.

Interviews in case studies allow the research to gain in-depth data, document multiple perspectives and experiences and explore contested issues [51]. Semi-structured in-depth interviews (Table 2) of at least an hour each were conducted with senior experts to gather expert opinions about the barriers and effectiveness of the implementation of Blockchain. Both purposive and network sampling were used to select interview participants. The in-depth interviews were conducted one-on-one and not as group interviews, as the research topic is emerging, and a group interview would suppress individual expert ideas on the subject.

Table 2. Interviewees list.

Interviewees Name	Interviewee Job Title
Conor McCarthy	Founder and Executive Chairman of Dublin Aerospace
Tony Conroy	Head of IT of Dublin Aerospace
Gerry White	Manager of Landing Gear Records and Materials
Nadzri Hashim	Group Head of Engineering AirAsia
Anonymous interviewee A	Project Manager at an aircraft manufacturer
Ramesh Sivasubramanian	VP Tech & Innovations-Frictionless AI, Blockchain, AR/VR, IoT-across Aviation MRO, ER
Brendan McKittrick	Chief Executive Officer at Aeroband
John Roberts	CEO of BlockAviation
Simon Mullaney	CTO & Co-founder BlockAviation
Anonymous interviewee B	MRO senior manager
Anonymous interviewee C	Aviation IT provider

Research ethics principles were followed. All interviewees were informed in an initial consent letter and before the interview commenced that they could opt out of the interview at any time. All the named interviewees consented to be named in the paper. A pilot study with an aircraft maintenance facility employee was carried out to identify any potential issues or problems affecting the study's overall findings.

4. Discussion of Findings

The findings are grouped and analyzed according to four main themes: (1) Current status of maintenance records management (case study); (2) The value of data storage within MROs; (3) Benefits of Blockchain within MROs; (4) Barriers to Blockchain implementation and organizational readiness.

4.1. Process of Maintenance Verification and Records Management at the Case Study of Dublin Aerospace

Based on in-depth interviews with Dublin Aerospace and visits to the facilities, we summarize in this section the current process of maintenance verification and records management. Dublin Aerospace records the maintenance work completed as part of the maintenance process for the aircraft and components they service. They provide these records in both hard and soft copies as per their contractual obligations. McCarthy, CEO of Dublin Aerospace, stated that they currently manage their maintenance records in a traditional sense. In other words, they have a paper record known as the original document, and they also input the record into their maintenance system, which is called DALsys. The DALsys system records all the work and inspections on the aircraft, APU and landing gears. Conroy, Head of IT Dublin Aerospace, clarified that the records include details such as who provided the service, as well as who inspected it and when. It is a legal and regulatory requirement to have all maintenance records completed. The Irish Aviation Authority lays out the requirements for signing off maintenance tasks, and the organizations must adhere to these. Dublin Aerospace uses Microsoft office suite, Word and Excel to support reports and data production.

All maintenance completed must be physically inspected and authenticated using a password and stamp combination. Dublin Aerospace uses a stamp with a particular reference number to verify that the work is conducted. When they sign off on the work, that card is stamped with a specific reference number. The work itself does not always have to be completed by the approved personnel but must be inspected by personnel authorized by the regulatory authority to do so. For example, an aircraft engineer with a license on the Boeing 737–300 can sign off particular work within their competence on a 737–300. They also need company approval from Dublin Aerospace to stamp that work. Thus, a significant number of tasks are subject to a duplicate/dual inspection. Two individuals will sign off and stamp the work completed and inspected in a duplicate inspection. Approved personnel are required by quality assurance to complete periodic continuation training to keep their approval licenses up to date, and Dublin Aerospace requires them to pass an internal quality assurance process. They must maintain that approval by keeping it current and complying with regular training. Verifying records by signing off and stamping work completed and inspected ensures that the maintenance record employees can track the individuals who completed and inspected the work.

Conroy, Head of IT of Dublin Aerospace, stated that the repetitiveness of tasks during record management causes some frustration. The hardcopy data and scanning process management can be cumbersome and inefficient because customers can document in different formats. McCarthy believes that the system has built-in inefficiencies. If an engineer, technician or owner, for instance, wants to look for a specific record to demonstrate work completed on a certain date to a particular standard in the maintenance manual, they will look for the paper record, also known as the dirty fingerprint, and if this is not located, this work will no longer be accepted as completed.

4.2. The Value of Data Storage within the Aviation Industry

All interviewees agreed that data storage within aircraft maintenance is a legal and regulatory requirement. White, Manager of Landing Gear Records and Materials, states data storage is critical as it is mandatory to keep all maintenance records for a minimum of three years. However, most MROs, airlines and operators will keep these records for much longer. McCarthy stated that data within the aviation industry is still paper to a great extent. All the records hold data, which is critical to ensure the airworthiness of the aircraft and to meet commercial requirements that have grown with time.

According to White, the owners and lessors of aircraft demand back to birth aircraft and component records, particularly when it comes to the end of a lease and transfer of ownership. A full back-to-birth record must cover all aircraft and aircraft components before being used and classified as airworthy. This includes an up to date certification by an approved repair station, as explained by McCarthy. There are also limited life parts on both landing gears and APUs. MROs and the industry at large must track and trace the maintenance history and times achieved on each life-limited part. According to White, in the case of landing gears, the industry must keep records indefinitely due to the industry's back-to-birth requirements.

The interviewees also identified the lack of industry standards in data storage as a significant issue. Convoy said, 'Full back to birth records and all trace records can be a big issue within the aviation industry'. Duplication of work is a huge unnecessary expense for aircraft operators. Suppose a scheduled inspection or maintenance is not completed correctly or recorded correctly within the aircraft's maintenance records. In that case, the maintenance will be repeated, or time will be spent chasing down a maintenance record.

Accurate and complete maintenance records have a significant impact on the operational costs of an aircraft and the overall value of the aircraft. Incomplete or missing records will significantly impact value and the ability to sell an aircraft or parts. Hashim, Group Head of Engineering AirAsia, said that 'Data is the value of the aircraft', and Anonymous interviewee A said that 'Records are things we can control'. McCarthy stated that records and data are vital as a company needs to be confident that they can locate the data at any time and ensure the data will not be lost or corrupted.

4.3. Benefits of Blockchain Technology for MRO's

All the interviewees reported that Blockchain technology could be a massive benefit within MRO's. McKittrick, CEO of Aeroband, a company developing AEROBLOC (Distributed Ledger Technology), said that Blockchain would fundamentally change the industry. He claimed that Blockchain allows competitors to collaborate for the first time. Hashim stated that if a part malfunctions, the technician or engineer working on that particular part could use Blockchain to track the history of the part (e.g., flight hours, date it was last replaced or repaired, etc.) to decide if they should repair or replace the part. Blockchain would enable the records to be linked to the aircraft and, therefore, ensure the aircraft's value is intact. McCarthy believes that Blockchain could practically and theoretically replace the management and storage of records. It could store data in encrypted forms, making it impossible to tamper with the data. Retrieving data would be relatively secure from any location globally, depending on your participation in the chain. Sivasubramanian, VP Tech & Innovations, suggests that Blockchain can protect private data and complies with all the terms of record keeping. All interviewees stated that transparency is a vital element valuable in the MRO industry.

McCarthy stated, 'The fact that Blockchain technology is decentralized, encrypted and transparent makes it the perfect fit for something as valuable as an aircraft maintenance record'. Blockchain would speed up data retrieval and record processing because everything is encrypted. Sivasubramanian noted that Blockchain would assist with capturing the expiry dates of parts. In terms of retrieving data, McCarthy stated that it would be much easier to find a record using Blockchain instead of going through a tremendous amount of paper records, which takes up a lot of time. It would also prevent records from being damaged or mislaid. All the interviewees agreed that Blockchain would remove unnecessary steps, speed up recovering data and prevent the damaging or loss of records.

All participants recognized that smart contracts could bring significant benefits to MROs. All aircraft and component maintenance is completed based on a contract agreed and signed off before any work is released. McCarthy outlined the process Dublin Aerospace uses when preparing contracts. Usually, they receive a proposal from a customer which includes a work package detailing what they want to be completed. The work package is broken down and estimated, based on labour materials and how long and to what extent the hangar will be occupied by the aircraft or component. White highlighted that the contract proceedings could be complicated, as there are many types of contracts according to customer requirements and many steps until the terms and conditions are agreed with the customer. All the interviewees from Dublin Aerospace confirmed that it is challenging to monitor contracts.

According to Anonymous interviewee A, implementing smart contracts could make the whole process more efficient by saving time and money. White and Conroy suggest that smart contracts could work in the industry, particularly simpler contracts. More specifically, smart contracts can overhaul a single component or aircraft overhaul where all materials and labour costs are known and all the conditions and parameters of landing gear and APU are determined in advance. McCarthy believes that using smart contracts would be a significant assistance, stating that it would take out any additional discussion about costs over a piece of work once it is approved.

Sivasubramanian highlighted another essential benefit of smart contracts: faster negotiation of contracts. All interviewees agreed that digital signatures could provide a more efficient, transparent and safer way to sign off maintenance tasks. Conroy stated that there are several areas where digital signatures could be implemented. For example, additional work not included in the original contract is needed during an aircraft overhaul process. A customer representative does not need to be onsite to sign the additional work form but can instead use a digital signature remotely. Digital signatures can reduce costs since it is costly for both MRO and customers to have onsite representatives.

The paper-based system has many flaws. Situations where an approved inspector loses their unique stamp can be avoided. Digital signatures can prevent an individual from inadvertently signing off inspection for a task that has not been approved. The digital approach would cross-check the approval with the individual and therefore reject inspections by anyone not suitably authorized. By having a digitally encrypted signature, the traceability of the individual and security are assured.

4.4. Barriers to Implementation and Organizational Readiness Evaluation

There are several potential barriers to Blockchain implementation. Information sharing was a barrier mentioned by all participants. According to McCarthy, stakeholders in the aviation industry do not share data or records with businesses that they are not directly involved with. Sivasubramanian argues there is a lack of trust between the parties, and McKittrick argued that the main challenge is to bring the whole industry onto the same page. Transparency and traceability, the main features of Blockchain, can lead to liability issues as they allow the more truthful identification of a problem. McKittrick also highlighted that aviation companies are safety cautious and afraid of disruptions. Therefore, the industry is slow to accept change. As Hashim mentioned, Blockchain does not work without collaboration and community. Therefore, trust and information sharing is the most critical obstacle to Blockchain technology.

One of the significant obstacles in implementing Blockchain that all participants identified is the regulatory complexity within the aviation industry. The participants all stated that regulators would be slow to accept Blockchain. They acknowledged that the regulatory body is trying to move in the right direction regarding digitalization, but it still does not have a worldwide approach. For instance, e-records are not accepted worldwide. There is currently a lack of clearly defined and standard regulations, especially regarding the Blockchain.

The cost of implementation was a significant barrier that arose with the participants. Conroy stated that many small spares trading distributors and repair agencies in the aerospace sector are critical to how the industry operates. The cost structure and inclusion in any effective consortium Blockchain may prove too prohibitive to these more minor players in the industry.

A concern that arose with several interviewees is the need for a dual system that accommodates both the old methods and Blockchain technology. The lack of buy-in from players in the industry could create fragmented and incomplete historical records that would cause a lack of confidence in the application of Blockchain. McCarthy highlighted the need for quality and accuracy of the data, and according to him, it is still uncertain to what extent Blockchain assures this.

Conroy and McKittrick noted that one of the barriers to a shared repository of maintenance history would be the interests of individual companies. AERDATA, for example, is a Boeing company that offers a software application for hosting and searching technical records. AirVault, a cloud-based digital aircraft records management company, belongs to GE. Aircraft manufacturers have significant investments in record-keeping companies.

Employees' resistance will always be a challenge when implementing a new technology. According to White and McCarthy, the initial stage of Blockchain technology adoption will require a considerable effort to transition from one system to the other, which may cause some frustration to employees. Another barrier was identified while selecting interviewees, and this is the lack of knowledge about Blockchain from the aviation practitioners. While some aviation practitioners may have a basic understanding of Blockchain, the individuals were unaware of the different types of Blockchain. Lack of awareness can act as a barrier to implementation.

According to some interviewees, the aviation industry is not ready to implement Blockchain records management. All participants agree that the aviation industry is slow to adapt to new changes. Conroy stated that historically due to the levels of regulation, the industry is slow to change and is not typically an early adopter of new technologies. Sivasubramanian, on the other hand, believes that MROs are ready and willing to implement Blockchain technology but argues that Blockchain has not matured to the extent that MROs would wish it to be. McKittrick stated that most Blockchain technology providers do not scale up and therefore face out. McCarthy believes that small independent MROs will find it difficult if they have to create their own Blockchain system and will not see the benefits for them of investing in new technology at present; this, however, may change over the next ten years.

White and Anonymous interviewee A believe that presently there is inadequate Blockchain expertise in the aviation industry. Conroy adds that to date, there is little or no sign of any knowledge in the area of Blockchain within the aircraft maintenance sector, but McCarthy states that there is sufficient 3rd party knowledge. This could hinder the implementation of Blockchain; however, with more modern low-cost operators demanding more agile, cost-effective services and solutions, there will soon be a new stream of experts who will develop this sector.

Conroy, White and McCarthy all agree that the OEMs need to start producing 'digital twins' very soon for their new aircraft, engines and major components such as APUs and landing gears from birth. Once the digital twin is created, the flight hours, cycles and maintenance events can be updated accordingly. McCarthy noted that the migration of old data to the Blockchain might take a lot of time and effort. Still, it is well justified for aircraft with a significant operating life remaining.

McCarthy also argues that Blockchain technology addresses the business requirements of MROs, and the emergence of many new Blockchain organizations can stimulate its implementation. Big MROs are already involved either as observers or contributors to Blockchain innovation. Small and independent MROs need to adapt and modernize their operations to ensure business survival.

4.5. Findings vs. Literature

In this section, we compare the research results from the study of MRO to the literature in the area of adoption challenges. Table 3 provides this comparison. We note that MROs (including Dublin Aerospace) do not deviate much from the challenges for adoption identified in the literature. The main difference and important finding are that the MRO experts seem to understand the benefits of Blockchain, despite not being completely familiar with the technicalities of this complex technology.

Table 3. Blockchain adoption challenges in supply chain systems.

Challenges	Explanation (Dutta et al., 2019)	MRO Example
Organizational requirement and readiness	Lack of understanding of benefits and technicalities involved and Limited knowledge of the complex technology.	• The MRO organization seems to understand the benefits, but not the technicalities and the technology itself. The technicalities understanding is not a parameter for not adopting the technology.
	• Still, an emerging technology and many successful implementation references are available.	• The lack of successful implementation references is noted in MRO too.
	• A perception that most problems can be solved using traditional information and database systems and there is no need for Blockchain.	• This is not the case for MROs.
Data collection and management	• Assuring the integrity of input data is a difficult task.	• This is a challenge that is noticed in traditional data management technologies too.
	• Convincing all stakeholders to share information is a challenge.	• This is a challenge for MROs too.
	• The organization of such vast amounts of data and its efficient use is a problem.	• This is a challenge that is noticed in traditional data management technologies too.
Interoperability of systems	• Multiple efforts are being taken in silos, and various Blockchain systems are being developed. Standardization of all these and ensuring smooth interoperability is a must. Otherwise, it will make things complicated instead of making them more straightforward.	• This applies to MROs too.
Cost, security, privacy and legal concerns	• Organization-wide technology change and adoption are costly and time-consuming.	• MROs have emphasized this.
	• The technology is still very immature and vulnerable. Privacy and security of models and data need to be ensured.	• This is recognized by the MROs too.
	• Regulatory uncertainty can cause a lot of unwanted complications	• This is recognized by the MROs too.
	• Potential for an organization-wide hit if the system fails	• This applies to MROs too.
	• Blockchain should be applied selectively after weighing in the economics of implementation in terms of both cost and risk	• This applies to MROs too.

Table 3. *Cont.*

Challenges	Explanation (Dutta et al., 2019)	MRO Example
Transition and integration of people, processes and technology	• It is a considerable change in all aspects of an existing business. • Many stakeholders are involved, and changing old mindsets, culture and work methodologies is a big issue. • There can be conflicting objectives for different stakeholders. • Intermediators involved at various levels might be eliminated, which can create rifts. • Uncertainty and lack of awareness hamper acceptance. • A perception that Blockchain implementation might lead to loss of jobs.	• These apply to MROs too.

5. Conclusions, Implications and Recommendations

This research has a few important implications for scholars and practitioners. It provides insights into the benefits of Blockchain technology, the data management needs of MROs and how these two are linked. This study has outlined how Blockchain works from a theoretical perspective and has identified its benefits. Blockchain is an immutable, decentralized and secure database where the information stored in the database cannot be altered. Its content cannot be replaced in all the nodes associated with the network. Blockchain has gained momentum with end-to-end visibility and traceability, decentralization, enhanced data security, decision making, knowledge sharing, end-to-end integration and management being the primary focus areas [17].

Blockchain technology has enormous potential and managerial implications. The research suggests that transparency, speed and efficiency of data retrieval is a significant benefit of Blockchain. The immutable nature of Blockchain technology is a guarantee of its authenticity, which is paramount within the MRO industry. This eliminates the subsequent problems of counterfeit parts and fraud.

Blockchain has important implications for MRO managers. Blockchain provides MRO managers, inspectors and policymakers with timely information. A full back-to-birth record is required for any aircraft and components; the records must be accurate and up to date before the aircraft or component is considered airworthy. A significant issue within the aviation industry is mislaid or damaged records, which can affect the overall value of an aircraft or aircraft parts. The results of the interviews and secondary research prove that if records were stored on a Blockchain, this could remove the risk of records being mislaid or damaged. Blockchain technology offers the capacity to create a digital twin for any record for a part or aircraft.

The use of smart contracts in MRO is identified as a significant benefit. Smart contracts would be a tremendous assistance when the work gets authorized, signed off and automatically invoiced. Smart contracts have many benefits, including efficiency, accuracy and cost savings. Blockchain could revolutionize record management within MRO.

Nevertheless, this research found that MROs are not ready to implement Blockchain technology. The lack of technology familiarity and the high investment cost hinder Blockchain implementation in MROs. Despite its long-term benefit, small independent MROs will not invest in Blockchain in the short term, as the implementation cost is too high. The research also identified several barriers to implementation. Information sharing and lack of trust are barriers, as many stakeholders are unwilling to share data about their aircraft or components with third parties. Some parties have vested interests; Blockchain may reduce profits for companies with other technologies already in the market. The current regulatory framework on Blockchain technology is underdeveloped, and the aviation industry is risk-averse.

Blockchain technology has an immense potential to enhance MRO business. Blockchain can streamline business processes and reduce friction in conducting business internally and externally. It can break down silos and provide a collaborative platform. Building an aircraft supply-chain wide consortium to develop and use Blockchain collectively can assist the standardization and deployment of Blockchain. At the same time, though, MROs should not get carried away and switch entirely to the Blockchain without assuring interoperability of the systems for contingency reasons. There will be many collaborators that will not yet adopt Blockchain technology. Therefore, existing digital aircraft records solution providers should develop interoperable Blockchain technologies that allow better integration of systems while keeping the cost of investment low.

Standardization is necessary. There needs to be agreement on the data interoperability, data interface, architecture and intelligent decision-making standards. Moreover, there needs to be compliance with national and international entities' legal and regulatory rules, such as the European Aviation Safety Agency (EASA), the Federal Aviation Administration (FAA), and other Civil Aviation Authorities. A governance framework can help define and regulate how information on the Blockchain is stored, accessed and shared. Stakeholders' trust and willingness to share data can be a significant challenge. Clearly outlining the common benefit of Blockchain adoption and the rules for data management will build stakeholders' trust.

Moreover, Blockchain developers should create widely shared use-cases for MROs. A use-case would showcase why an organization needs Blockchain and how Blockchain can contribute to optimized processes. This will also contribute to a better understanding of which specific Blockchain functionalities are more helpful for MROs. Blockchain developers should also focus on how the data flows and is used, who is using it and users' needs. A positive step towards that direction is the MRO Blockchain Alliance, which brings together the various stakeholders and aims to set a global standard around the use of Blockchain.

Some Blockchain functionalities can be too complicated because of all the modifications. Many customers and employees are not familiar with this technology, which can lead to resistance to change. IATA frequently hosts events on digital aircraft operations, and employees should be encouraged to participate in these events. Educating employees should be a priority when implementing any new system. Knowledge amongst management and employees of MROs will provide ultimate benefits.

Blockchain is still a new technology, and to shed light on this under-researched field, further research is needed in this area. Use cases on the implementation of Blockchain in MRO or lessons learned for MRO would advance our knowledge in the area. Alternative research using the Technology Acceptance Model (TAM) to identify the extent to which MRO employees and clients are using such technology could also garner insight.

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References

1. Saberi, S.; Kouhizadeh, M.; Sarkis, J.; Shen, L. Blockchain technology and its relationships to sustainable supply chain management. *Int. J. Prod. Res.* **2019**, *57*, 2117–2135. [CrossRef]
2. Vieira, D.R.; Loures, P.L. Maintenance, repair and overhaul (MRO) fundamentals and strategies: An aeronautical industry overview. *Int. J. Comput. Appl.* **2016**, *135*, 21–29.

3. Lootens, K.J.B.; Efthymiou, M. The adoption of network-centric data sharing in air traffic management. In *Research Anthology on Reliability and Safety in Aviation Systems, Spacecraft, and Air Transport*; IGI Global: Hershey, PA, USA, 2021; pp. 127–151.
4. Gurtu, A.; Johny, J. Potential of blockchain technology in supply chain management: A literature review. *Int. J. Phys. Distrib. Logist. Manag.* **2019**, *49*, 881–900. [CrossRef]
5. Min, H. Blockchain technology for enhancing supply chain resilience. *Bus. Horiz.* **2019**, *62*, 35–45. [CrossRef]
6. PWC. Blockchain Is Here. What's Your Next Move? 2018. Available online: https://www.pwc.com/gx/en/issues/blockchain/blockchain-in-business.html (accessed on 24 November 2019).
7. Hughes, L.; Dwivedi, Y.K.; Misra, S.K.; Rana, N.P.; Raghavan, V.; Akella, V. Blockchain research, practice and policy: Applications, benefits, limitations, emerging research themes and research agenda. *Int. J. Inf. Manag.* **2019**, *49*, 114–129. [CrossRef]
8. Kuo, T.-T.; Kim, H.; Ohno-Machado, L. Blockchain distributed ledger technologies for biomedical and health care applications. *J. Am. Med. Inform. Assoc.* **2017**, *24*, 1211–1220. [CrossRef] [PubMed]
9. Wamba, S.F.; Queiroz, M.M. Blockchain in the operations and supply chain management: Benefits, challenges and future research opportunities. *Int. J. Inf. Manag.* **2020**, *52*, 102064. [CrossRef]
10. Yang, C.-S. Maritime shipping digitalization: Blockchain-based technology applications, future improvements, and intention to use. *Transp. Res. Part E Logist. Transp. Rev.* **2019**, *131*, 108–117. [CrossRef]
11. Clementi, M.D.; Larrieu, N.; Lochin, E.; Kaafar, M.A.; Asghar, H. When air traffic management meets blockchain technology: A blockchain-based concept for securing the sharing of flight data. In Proceedings of the IEEE/AIAA 38th Digital Avionics Systems Conference (DASC), San Diego, CA, USA, 8–12 September 2019; pp. 1–10.
12. Zakir, Y.; Hasan, K.S.; Wiggins, N.S.; Chatterjee, A. Improving data security in message communication between ACT and aircraft using private Blockchain. In Proceedings of the 2019 Sixth International Conference on Internet of Things: Systems, Management and Security (IOTSMS), Granada, Spain, 22–25 October 2019; pp. 506–513.
13. Schyga, J.; Hinckeldeyn, J.; Kreutzfeldt, J. Prototype for a permissioned blockchain in aircraft MRO. In Proceedings of the Hamburg International Conference of Logistics (HICL), Hamburg, Germany, 26–27 September 2019; pp. 469–505.
14. Mandolla, C.; Petruzzelli, A.M.; Percoco, G.; Urbinati, A. Building a digital twin for additive manufacturing through the exploitation of Blockchain: A case analysis of the aircraft industry. *Comput. Ind.* **2019**, *109*, 134–152. [CrossRef]
15. Wang, Y.; Singgih, M.; Wang, J.; Rit, M. Making sense of blockchain technology: How will it transform supply chains? *Int. J. Prod. Econ.* **2019**, *211*, 221–236. [CrossRef]
16. Frizzo-Barker, J.; Chow-White, P.A.; Adams, P.R.; Mentanko, J.; Ha, D.; Green, S. Blockchain as a disruptive technology for business: A systematic review. *Int. J. Inf. Manag.* **2020**, *51*, 102029. [CrossRef]
17. Dutta, P.; Choi, T.M.; Somani, S.; Butala, R. Blockchain technology in supply chain operations: Applications, challenges and research opportunities. *Transp. Res. Part E Logist. Transp. Rev.* **2020**, *142*, 102067. [CrossRef] [PubMed]
18. Canaday, H. Blockchain in MRO Could Happen Sooner Than You Think. 2017. Available online: https://www.mro-network.com/big-data/blockchain-mro-could-happen-sooner-you-think (accessed on 24 November 2019).
19. Yang, R.; Wakefield, R.; Lyu, S.; Jayasuriya, S.; Han, F.; Yi, X.; Yang, X.; Amarasinghe, G.; Chen, S. Public and private Blockchain in construction business process and information integration. *Autom. Constr.* **2020**, *118*, 103276. [CrossRef]
20. Kehoe, L.; Hallahan, J. Blockchain—A Game Changer in Aircraft Leasing. 2018. Available online: https://www2.deloitte.com/content/dam/Deloitte/ie/Documents/Tax/ie-blockchain-a-game-changer-in-aircraft-leasing.pdf (accessed on 16 February 2019).
21. Zheng, Z.; Xie, S.; Dai, H.; Chen, X.; Wang, H. An overview of blockchain technology: Architecture, consensus, and future trends. In Proceedings of the 2017 IEEE International Congress on Big Data (BigData Congress), Boston, MA, USA, 11–14 December 2017; pp. 557–564.
22. Dupont, Q. Blockchain identities: Notational technologies for control and management of abstracted entities. *Metaphilosophy* **2017**, *48*, 634–653. [CrossRef]
23. Cong, L.W.; He, Z. Blockchain disruption and smart contracts. *Rev. Financ. Stud.* **2019**, *32*, 1754–1797. [CrossRef]
24. Abadi, J.; Brunnermeier, M. *Blockchain Economics*; (No. w25407); National Bureau of Economic Research: Cambridge, MA, USA, 2018.
25. Xiong, L.; Liu, L. PeerTrust: Supporting reputation-based trust for peer-to-peer electronic communities. *IEEE Trans. Knowl. Data Eng.* **2004**, *16*, 843–857. [CrossRef]
26. Yuan, Y.; Wang, F.Y. Towards blockchain-based intelligent transportation systems. In Proceedings of the 2016 IEEE 19th International Conference on Intelligent Transportation Systems (ITSC), Rio de Janeiro, Brazil, 1–4 November 2016; pp. 2663–2668.
27. Li, J.; Wu, J.; Chen, L. Block-secure: Blockchain based scheme for secure P2P cloud storage. *Inf. Sci.* **2018**, *465*, 219–2311. [CrossRef]
28. Liu, B.; Yu, X.L.; Chen, S.; Xu, X.; Zhu, L. Blockchain based data integrity service framework for IoT data. In Proceedings of the 2017 IEEE International Conference on Web Services (ICWS), Honolulu, HI, USA, 25–30 June 2017; pp. 468–475.
29. Deloitte. Continuous Interconnected Supply Chain: Using Blockchain & Internet-of-Things in Supply Chain Traceability. 2017. Available online: https://www2.deloitte.com/content/dam/Deloitte/lu/Documents/technology/lu-blockchain-internet-things-supply-chain-traceability.pdf (accessed on 3 March 2019).
30. Alkhudary, R.; Brusset, X.; Fenies, P. Blockchain in general management and economics: A systematic literature review. *Eur. Bus. Rev.* **2020**, *32*, 765–783. [CrossRef]

31. Davidson, S.; De Filippi, P.; Potts, J. Blockchains and the economic institutions of capitalism. *J. Inst. Econ.* **2018**, *14*, 639–658. [CrossRef]
32. Treiblmaier, H. The impact of the blockchain on the supply chain: A theory-based research framework and a call for action. *Supply Chain Manag. Int. J.* **2018**, *23*, 545–559. [CrossRef]
33. Kamble, S.; Gunasekaran, A.; Arha, H. Understanding the Blockchain technology adoption in supply chains—Indian context. *Int. J. Prod. Res.* **2019**, *57*, 2009–2033. [CrossRef]
34. Straub, E.T. Understanding technology adoption: Theory and future directions for informal learning. *Rev. Educ. Res.* **2009**, *79*, 625–649. [CrossRef]
35. Taherdoost, H. A review of technology acceptance and adoption models and theories. *Procedia Manuf.* **2018**, *22*, 960–967. [CrossRef]
36. Lai, P.C. The literature review of technology adoption models and theories for the novelty technology. *JISTEM-J. Inf. Syst. Technol. Manag.* **2017**, *14*, 21–38. [CrossRef]
37. Toufaily, E.; Zalan, T.; Dhaou, S.B. A framework of blockchain technology adoption: An investigation of challenges and expected value. *Inf. Manag.* **2021**, *58*, 103444. [CrossRef]
38. Rogers, E. *Diffusion of Innovations*, 5th ed.; Free Press: New York, NY, USA, 2003.
39. Khan, R.A.; Qudrat-Ullah, H. Technology adoption theories and models. In *Adoption of LMS in Higher Educational Institutions of the Middle East*; Springer: Cham, Switzerland, 2021; pp. 27–48.
40. Lippert, S.; Forman, H. Utilization of information technology: Examining cognitive and experiential factors of post-adoption behavior. *IEEE Trans. Eng. Manag.* **2005**, *52*, 363–381. [CrossRef]
41. EFNMS. MRO Definition—European Federation of National Maintenance Society. 2013. Available online: http://www.efnms.org/ (accessed on 17 November 2018).
42. Shafiee, M.; Chukova, S. Maintenance models in warranty: A literature review. *Eur. J. Oper. Res.* **2013**, *229*, 561–572. [CrossRef]
43. Kinnison, H.A.; Siddiqui, T. *Aviation Maintenance Management*, 2nd ed.; McGraw-Hill: New York, NY, USA, 2012.
44. Federal Aviation Administration. AC 43-9C. Maintenance Records—Document Information. 2018. Available online: https://www.faa.gov/regulations_policies/advisory_circulars/index.cfm/go/document.information/documentID/22587 (accessed on 27 November 2018).
45. Madhwal, Y.; Panfilov, P.B. Industrial case: Blockchain on aircraft's parts supply chain management. In Proceedings of the American Conference on Information Systems 2017 Workshop on Smart Manufacturing, Boston, MA, USA, 10–12 August 2017; Volume 6.
46. Sletten, S. Suspected unapproved parts in the aviation industry: Consideration of system safety and control. *J. Aviat./Aerosp. Educ. Res.* **2000**, *9*, 4. Available online: https://pdfs.semanticscholar.org/ab1e/daab31d4a19422a93fe15d3c761fb34d7581.pdf (accessed on 5 March 2019).
47. Reuters. Fake Paperwork, Poor Parts Challenge China's Aerospace Boom. 2017. Available online: https://www.reuters.com/article/us-china-aviation-whistleblower-insight/fake-paperwork-poor-parts-challenge-chinas-aerospace-boom-idUSKBN1CL0R2 (accessed on 28 November 2018).
48. Adanov, L.; MaCintyre, A.; Efthymiou, M. An exploratory study of pilot training and recruitment in Europe. *Int. J. Aviat. Sci. Technol.* **2020**, *1*, 44–51. [CrossRef]
49. Corbet, S.; Efthymiou, M.; Lucey, B.; O'Connell, J.F. When lightning strikes twice: The tragedy-induced demise and attempted corporate resuscitation of Malaysia airlines. *Ann. Tour. Res.* **2021**, *87*, 103109. [CrossRef]
50. O'Connell, J.F.; Avellana, R.M.; Warnock-Smith, D.; Efthymiou, M. Evaluating drivers of profitability for airlines in Latin America: A case study of Copa Airlines. *J. Air Transp. Manag.* **2020**, *84*, 101727. [CrossRef]
51. Simons, H. Case study research: In-depth understanding in context. In *The Oxford Handbook of Qualitative Research*; Oxford University Press: Oxford, UK, 2014; pp. 455–470.
52. Efthymiou, M.; Usher, D.; O'Connell, J.F.; Warnock-Smith, D.; Conyngham, G. The factors influencing entry level airline pilot retention: An empirical study of Ryanair. *J. Air Transp. Manag.* **2021**, *91*, 101997. [CrossRef]
53. Khan, N.; Efthymiou, M. The use of biometric technology at airports: The case of customs and border protection (CBP). *Int. J. Inf. Manag. Data Insights* **2021**, *1*, 100049. [CrossRef]
54. Papatheodorou, A.; Vlassi, E.; Gaki, D.; Papadopoulou-Kelidou, L.; Efthymiou, M.; Pappas, D.; Paraschi, P. The airline–airport–destination authority relationship: The case of Greece. In *Tourist Destination Management*; Springer: Cham, Switzerland, 2019; pp. 27–41.
55. Jans, R.; Dittrich, K. A review of case studies in business research. In *Case Study Methodology in Business Research*; Dul, J., Hak, T., Eds.; Routledge: London, UK, 2007; pp. 19–29.
56. Shaw, M.; Tiernan, S.; O'Connell, J.F.; Warnock-Smith, D.; Efthymiou, M. Third party ancillary revenues in the airline sector: An exploratory study. *J. Air Transp. Manag.* **2020**, *90*, 101936. [CrossRef]
57. Murphy, G.; Efthymiou, M. Aviation safety regulation in the multi-stakeholder environment of an airport. *J. Air Transp. Stud.* **2017**, *8*, 1–26. [CrossRef]