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BLOCKCHAIN

AIRCRAFT SPARE PART MANAGEMENT

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M.Sc. Management of Technology

Blockchain for aircraft spare part management: Evaluating the robustness of the Maintenance, Repair and Overhaul business model

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"And if all others accepted the lie which the Party imposed—if all records told the same tale—then the lie passed into history and became truth. 'Who controls the past' ran the Party slogan, 'controls the future: who controls the present controls the past.'"

Orwell, G. (1949). *Nineteen Eighty-Four.* London: Secker & Warburg

Foreword

It has been an honour to work on this research, as the idea of a Blockchain-related research was conceived in the summer of 2017. This research was a perfect opportunity to refine my expertise and knowledge in aviation maintenance and combine it with a new emerging technology, such as Blockchain. Throughout the months, the research went through numerous iterations, which had been an insightful and enriching experience. As a result, this process allowed me to evaluate my work much more critically and academically, a competence I did not have before.

This research helped me truly understand what Management of Technology means in a business context. Jumping away from academic books to engage in practical business research is something I would recommend for any graduating student, especially if the opportunity exists to conduct research at a company. I was lucky to be able to do this research at Accenture Strategy, where I was given the necessary facilities in order to acquire my data. This experience also helped me think more as a consultant by trying to be more effective in my communication, which I tried to reflect throughout my research.

I am glad I was given the opportunity to develop an Accenture whitepaper and an academic paper based on this research. These documents can be acquired on request. In the end, I hope you perceive this work as one of quality and hope that you will enjoy reading this work as much as I enjoyed working on it.

Dusan Rajkov,
Amsterdam, 06-09-2018

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This graduate thesis describes the methodologic approach to evaluate the impact of Blockchain on the Maintenance, Repair and Overhaul business model. However, the challenges of this journey could not have been surpassed without a number of people that directly or indirectly supported me and my research.

When I decided to pursue a Blockchain-related research, I understood that it would be difficult to construct a committee of supervisors that would share this interest. This challenge was intensified when I decided to approach the niche aircraft Maintenance, Repair and Overhaul industry. For that reason, I would really like to provide my sincere gratitude to Prof.dr.ir. Lórant Tavasszy, Dr. Yousef Maknoon and Drs. Jolien Ubacht from the Delft University of Technology for their willingness and interest to be part of my graduation committee.

Yousef Maknoon had helped me critically evaluate the academic contribution of my research and helped me understand what it really meant to do scientific research. You helped me mitigate my competence gaps throughout our discussions and brainstorm sessions. I want to thank you for the time you made available for me and for being patient with the aviation-oriented research I wanted to pursue. Without your critical guidance, I would not have been able to engage in a research that would meet anyone's expectations. Your suggestion to publish my research as a paper in an international journal really helped me see opportunities in the field of academic research.

Jolien Ubacht had guided me throughout the graduation procedure, long before the research actually started. You guided me throughout the world of Blockchain and helped me explore potential research opportunities in this field of knowledge. I really appreciate that you had been able to not only give me, but also fellow students a platform through which we can share and discuss our Blockchain-related research. Your proactiveness and participation in Blockchain is what helps us get through our research.

Throughout the five months that resulted in the establishment of this thesis, Accenture Strategy had provided me the opportunity to be part of an international consultancy where I was able to refine my knowledge of Blockchain and the MRO landscape. I had to coordinate with fellow consultants and industry participants from the Netherlands, Germany, France, United Kingdom and United States. This coordination helped me to approach another consultancy, two MROs and an OEM. There are too many people I would like to thank for their contribution to my research. In particular, I want to thank Yorgos Roussakis, Arno Gideonse, Miel Geleijns, Marc Bonnet, Bhushan Bagde, Kjell Meershoek, Peter Wegbrands, Jeroen Ringlever, Craig Gottlieb, Jogchum Alberda, Yvo Steenberg and many others for their critical feedback and support. I want to thank both consultants and industry experts that agreed to participate in this research.

Yorgos Roussakis had guided me into the world of strategy consulting by challenging me to develop the mindset that is expected from Accenture. Arno Gideonse had guided me throughout the research by critically evaluating how we can identify opportunities of Blockchain within the aviation industry. I want to thank both of you for our regular meetings, which not only contributed to my research, but also gave me the morale and motivation to pursue excellence. I am grateful to have worked together with you.

Finally, I would like to provide sincere gratitude to people close to me who were patient during the five months and have been there to celebrate the victories together with me. I want to thank you for providing me with the guidance and support that helped me get through this challenging research.

EXECUTIVE SUMMARY

Research problem: Lack of transparency in the aviation supply chain and ecosystem

According to the International Air Transport Association (IATA), one of the important aspects of aircraft spare part management is tracking and tracing components throughout its lifecycle. However, this is problematic and complex for the following reasons:

- Nature of aircraft configuration: Modern aircraft can contain more than a million components and unique spare part numbers;
- Nature of spare part management: Components can be installed, removed, repaired, maintained, stored and shipped within the organisation or across the supply chain;
- Nature of aviation supply chain: Component maintenance and logistics coordination is a challenge due to the complex, distributed, multi-stage and international nature of the aviation supply chain;
- Nature of communication: Component data is typically shared by mail, web-based systems, storage media, paper or verbally among industry participants.

Due to the complexity of aircraft spare part management and lack of Inter-Organisational Information Systems to accurately track and trace aircraft spare parts, the aviation supply chain is not deemed as transparent as desired. As a result, proprietary maintenance information is not immediately available and participants face additional costs.

Research objective: Evaluating robustness of the MRO Business Model

Unfortunately, Radio Frequency Identification (RFID) and Internet of Things (IoT) solutions are limited to solve the problem of transparency, since it faces limitations surrounding information synchronisation, data access and security. As a result, Original Equipment Manufacturers (OEM), Maintenance, Repair and Overhaul (MRO) providers and aircraft operators consider using Blockchain to track and trace aircraft spare parts. Academic literature provides no insight on how Blockchain as an aircraft spare part track and trace capability could impact robustness of the MRO business model. This research aims to address that concern and contribute to literature on aircraft spare part management, Blockchain technology and business models.

Research scenario: Blockchain to track and trace aircraft spare parts

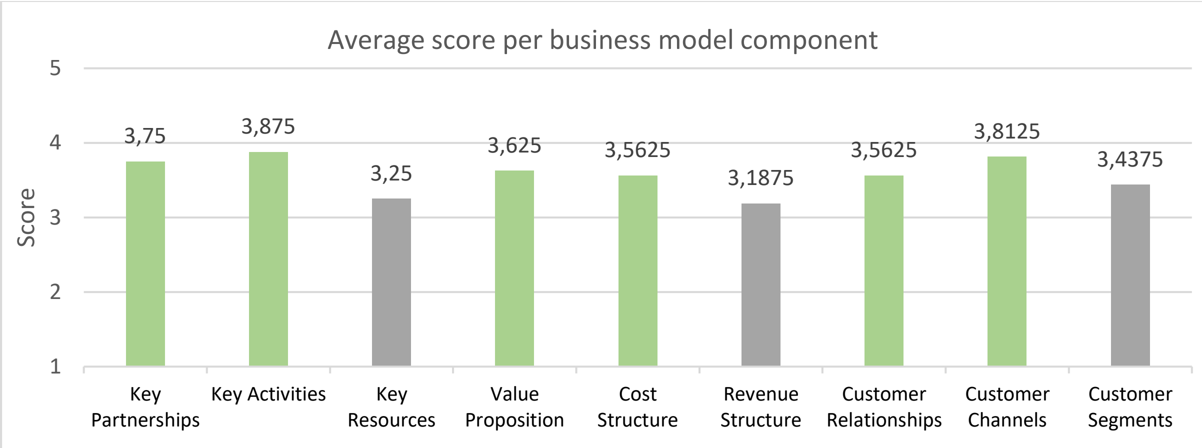
Through theoretically grounded research, a Blockchain use case was hypothesised on the premise that it can improve organisational performance through information sharing practices that improves aviation supply chain and ecosystem transparency. With the capability to hash both tangible (e.g. aircraft spare parts) and intangible (e.g. Certificate of Airworthiness) assets, Blockchain can be extended to the MRO industry as an aircraft spare part track and trace capability. This concept is already used to track and trace cars (e.g. Bitcar), coffee beans (e.g. Tony Chocolonely) and diamonds (e.g. Everledger). It can function as an inter-organisational digital distributed component logbook among known and trusted supply chain participants in a secure and controlled network where component RFID-based traceability data and IoT-based reliability data can be exchanged. All participants can use this real-time, accurate and complete data set to review aircraft spare part movement, ownership and condition.

Research protocol: Systematic MRO Business Model Evaluation

This research adopts a concurrent nested mixed method, since it facilitates the debate of deep Blockchain interventions through interviews and surveys. The design is guided by a conceptual model that incorporates the theoretical framework to construct the scenario: the application of Blockchain to track and trace aircraft spare parts. The design also incorporates an evaluation methodology that guides the research: Business Model Stress Test and an MRO Business Model Canvas. To safeguard the validity and reliability of the research, the research collects both qualitative-based interview data and quantitative-based survey data from sixteen knowledgeable MRO industry experts from two consultancies, an airline-owned MRO, an independent MRO and an OEM.

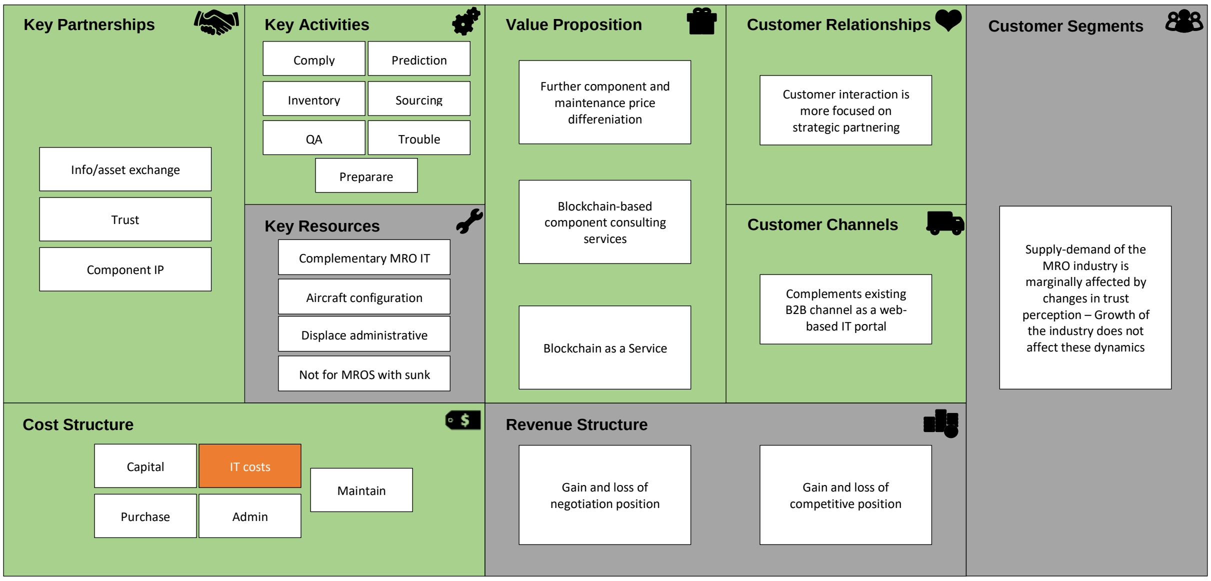
Research results 1: Strategic impact of Blockchain on the MRO business model

Through sixteen interviews with consulting and industry participants, the strategic impact of Blockchain as an aircraft spare part track and trace capability on the MRO business model is evaluated. In general, the participants are positive about the impact of Blockchain on the MRO business model, as can be seen in the chart below.



Average score per business model component

The figure above can be reformatted into the MRO Business Model Canvas, as seen in the figure below. However, this figure is insufficient to fully discuss how and why Blockchain affects a business model component in a certain way. Chapter 5 provides an extensive qualitative insight on how the 27 strategic areas are affected by Blockchain.



MRO Business Model Canvas: Blockchain impact

Research results 2: Robustness of the MRO business model

A sub-view analysis on the rows of the heat map shows that the MRO business model is considered robust, since 1) two components are robust in all scenarios; 2) five components are not robust in one out of six scenarios; 3) only two components are not robust in two out of six scenarios. This shows that the MRO faces a trade-off between its key maintenance activities and its cost and revenue structures. A sub-view analysis on the columns of the heat map shows that the MRO business model cannot be pressured by Blockchain alone, but rather by the premise of extensive data exchange. Additionally, given the importance of the network effect and regulatory nature of the MRO industry, MROs can only perceive noticeable improvements to their business model when the industry and institutions supports Blockchain.

A pattern analysis of the heat map below shows that MROs should opt for a regulatory-backed solution where only traceability and logbook data are exchanged throughout the entire industry. Additionally, the pattern analysis shows that four business model components are consistently impacted in all outcomes of data exposure and two business model components in all outcomes of regulatory support. Finally, by evaluating the best-case scenario, where limited data is shared through Blockchain with industry and regulatory support, three business model components are identified that are internally inconsistent throughout the scenarios.

MRO Business Model Heat Map

	Scenario	Blockchain as an aircraft spare part track and trace capability					
	Stress factors	Data exposure		Network support		Regulatory support	
	Outcomes	Limited	Sensitive	Limited	Industry	Limited	Support
Business model components	Key Partnerships	1A	1B	1C	1D	1E	1F
	Key Activities	2A	2B	2C	2D	2E	2F
	Key Resources	3A	3B	3C	3D	3E	3F
	Value Proposition	4A	4B	4C	4D	4E	4F
	Cost Structure	5A	5B	5C	5D	5E	5F
	Revenue Structure	6A	6B	6C	6D	6E	6F
	Customer Relationships	7A	7B	7C	7D	7E	7F
	Customer Channels	8A	8B	8C	8D	8E	8F
	Customer Segments	9A	9B	9C	9D	9E	9F

Research results 3: Feasibility of the Aviation Blockchain consortium

The feasibility of the Blockchain consortium depends on whether the aviation industry can address three main feasibility factors: the problem of data ownership; the need to incentivise parties; the opposition from regulatory institutions. This is captured in the table below.

Aviation Blockchain consortium feasibility evaluation

Feasibility factor	Concern	Problem
Problem of data ownership	Blockchain ownership Blockchain initiation	Parties claim ownership Parties present opportunism
Need to incentivise parties	Opposition from OEMs Opposition from Operators	Change in industry dynamics
Opposition from institutions	Opposition from EASA/FAA	Concern about data protocol

Unfortunately, the establishment of a Blockchain consortium faces different problems. The first problem is that industry participants already claim ownership over component data, which will not necessarily be solved with Blockchain since interaction and exchange between and among industry participants and institutions are limited and political in nature. The second problem is that industry participants possess an opportunistic nature: if Blockchain initiation and ownership is allocated to a specific party, they can exclude opposite parties from entering the Blockchain. The third problem is that industry participants are incentivised to not enter the Blockchain consortium. The fourth problem is that a Blockchain solution, where no party owns the data, will simply not be accepted by regulators that are concerned about data protocol. These problems are evident examples of the fragmented nature of the aviation industry, which might make it difficult to establish a Blockchain consortium. In order for the Blockchain consortium to be considered a feasible consideration, key industry parties must determine which component data is shared on the Blockchain and who would own that respective data segment. This shows that the initiation and ownership of the Blockchain should be distributed between industry participants and regulatory institutions in order to prevent opportunism in this stage. However, since a solution in which no party owns the data may not get accepted by regulators, it may be necessary to exclude authorities from the early stage of Blockchain adoption. It is necessary that Blockchain must first emerge as an industry standard, propelled and initiated by key industry participants and IATA. In a later stage, the EASA or FAA may be involved in order to maintain oversight over the Blockchain ecosystem and assure that all participants have the right capabilities to not pollute the ecosystem. However, until authorities are convinced that they can use Blockchain to remotely monitor and audit components, they will continue to emphasise paper records and signatures.

Research conclusion: Robustness of MRO business models in Blockchain consortiums

Blockchain as an aircraft spare part track and trace capability is not only strategically relevant for cost-conscious innovating MROs, it also does not impose a risk to the robustness of their business model in most scenarios. Blockchain complements RFID, IoT and existing MRO IT to solve the limitations of information synchronisation, data access and security. It would act as the architecture that allow MROs to meet their regulatory requirements and improve their maintenance activities. This would support the cooperation and trust between MROs, OEMs and operators through improved exchange activities and IP access. MROs would be able to differentiate themselves through Blockchain-based services and through calculated risk. Even though Blockchain could be seen as a web-based portal that can improve the interaction between an MRO and operators, they could lose their negotiation and competitive position. Through Business Model Stress Test, it was made clear that most business model components are robust in most scenarios. MROs should opt for a regulatory-backed Blockchain consortium where only traceability and logbook data are exchanged throughout the industry. If sensitive data is exchanged, this would threaten the MRO business model and incentivise them to not participate in the Blockchain consortium. This is one of the reasons why participants doubt whether component data will actually be shared, especially since it threatens the feasibility of the consortium. This shows that it is necessary to consider the robustness of the MRO business model in scenarios where a Blockchain consortium seems feasible. Unfortunately, due to the problem of data ownership, the need to incentivise parties and opposition from regulatory institutions, it might be a challenge to establish a Blockchain consortium.

Research discussion: Critical reflection on Blockchain limitations

Through literature, various Blockchain limitations were identified that were also recognised by interviewees, including scalability, privacy, immutability, storage, government regulation and business model alignment. Scalability is considered a problem once component reliability data is shared through the Blockchain. However, it is currently unknown how often aircraft spare parts are exchanged and whether scalability imposes a problem for these activities. Privacy is a major risk for industry negotiation and competitive dynamics, given the secretive and fragmented nature of the aviation industry. It is questionable whether MROs would accept these risks, especially since the underlying philosophy of Blockchain immutability conflict the maintenance philosophy of aircraft safety. This is because aircraft maintenance is focused on multiple checks to eradicate mistakes, which is not supported by Blockchain where immutability is a key property. Currently there are no solutions for this problem, which is why it is understandable why critics question Blockchain for aircraft spare part management. Additionally, the aviation industry provides emphasis on the location and distribution of data, which will become even more complicated with Blockchain. This shows the potential political opposition from regulatory institutions that emphasise data protocol. This factor could deteriorate Blockchain track and trace performance, as industry adoption may stall.

Research recommendation: Preparing MROs and academics for next steps in Blockchain

Even though Blockchain as an aircraft spare part track and trace capability does not affect the robustness of the MRO business model, MROs should take a certain position in the establishment of the Blockchain consortium to acquire the most favourable outcome. Once Blockchain emerges and matures, MROs should focus on regulatory-backed Blockchain consortium where limited component data is shared throughout the entire industry. Once more data is shared, the MRO business model will be pressured and puts them in the position to retreat from the consortium. Alternatively, they could proactively seek new cost and revenue models that can be leveraged by Blockchain (e.g. efficiencies in component maintenance administration) Since network support is important, future research should strategically focus on identifying incentives for other parties to consider Blockchain as an aircraft spare part track and trace capability. Furthermore, the findings of this research should be replicated by conducting interviews with a larger sample size, especially when Blockchain is entering widespread adoption.

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Aircraft Spare Part Management

#	Term	Definition
1.	Aircraft Spare Part Management	Activities related to the management of aircraft and engine inventories to assure that spare parts are available at the lowest costs for aircraft maintenance and prevent spare part related flight delays and cancellations.
2.	Aircraft Spare Parts	Airframe, engine or aircraft components that are monitored and maintained for the purpose of achieving airworthiness. These can be categorised in rotables (e.g. wheels), repairables (e.g. fire detector), expendables (e.g. lamps), recoverables (e.g. repairable expendables) and limited life parts (e.g. high-pressure turbine rotor disk).
3.	Airworthiness	A certification of airworthiness is provided by aviation regulators and is maintained by performing maintenance on the aircraft and its spare parts to assure safe flight conditions.
4.	Enterprise Resource Planning (ERP) system	Systems (e.g. SAP) to track business resources and the status of business commitments.
5.	European Aviation Safety Administration (EASA)	An agency of the European Union that is responsible for the regulation of civil aviation (e.g. aircraft certification, standardisation and monitoring).
6.	Federal Aviation Administration (FAA)	The national authority of the U.S. Department of Transportation that is responsible for the regulation of civil aviation (e.g. aircraft certification and construction).
7.	International Air Transport Association (IATA)	An entity that provides the aviation industry with global standards and vision regarding aircraft safety, sustainability, efficiency and security.
8.	Internet of Things (IoT)	Interconnection of devices that can be uniquely identified with an Internet Protocol address, and thus are connected to the internet.
9.	Maintenance, Repair and Overhaul (MRO) providers	Entities that are responsible for maintaining, repairing, inspecting and modifying unserviceable aircraft, engine and components to secure airworthiness and dispatch serviceable components.
10.	Original Equipment Manufacturer (OEM)	Entities that are responsible for manufacturing aircraft (e.g. Boeing), engines (e.g. General Electric) and components (e.g. Honeywell) for MRO providers.
11.	Radio Frequency Identification (RFID)	An electromagnetic based method to identify and track tags attached to physical objects with asset-specific data.
12.	Spec 2000	A Business-to-Business communication and data exchange standard proposed by IATA, which establishes which information must be shared during any transactions that significantly affects the condition or ownership of the aircraft spare part.
13.	Traceability data	Spec 2000 compliant information on part location, ownership, maintenance and usage history that is exchanged throughout the aircraft spare part lifecycle.
14.	Tracing	Determining the historical state and origin of an aircraft spare part by analysing traceability data.
15.	Tracking	Determining the current state of an aircraft spare part.

Blockchain Technology

#	Term	Definition
1.	Bitcoin protocol	Decentralised digital currency that relies on cryptographic hash functions rather than trust to computationally register and confirm electronic transactions without intermediaries.
2.	Blockchain consortium	A private permissioned Blockchain network in which there are restrictions on which organisations can read, write and validate data on the Blockchain.
3.	Blockchain technology	Cryptographic distributed ledger database that facilitates the transaction of value between network participants and validates the transactions with consensus mechanisms that remove the need of intermediaries.
4.	Ethereum protocol	Blockchain-based computing platform with a Turing-complete programming language that enables smart contracts.
5.	Hash function	Mathematical, computational algorithm that processes binary strings of arbitrary length to binary strings of fixed length that acts as the digital fingerprint.
6.	Smart contracts	Business rules that are embedded in computer-code and programmes that are then cryptographically computed on the Blockchain to provide autonomy, self-sufficiency and decentralisation.
7.	Smart properties	By hashing tangible (e.g. vehicles, real-estate, electronics) and intangible assets (e.g. copyrights, commodities, certifications) it is possible to track and control these assets on the Blockchain.

Business Model Stress Test

#	Term	Definition
1.	Business Model	Description or model that represents an enterprise's logic to create, distribute and capture value for its stakeholders.
2.	Business Model Innovation	Developing a new source of competitive advantage in environments characterised by technical, regulatory, competitive and market changes.
3.	Business Model Stress Test	The only known academic approach to evaluate the robustness of business models against stress factors, with the end goal to create a heat map.
4.	Feasibility	Relates to whether resources are available to implement and deploy the business model in practice.
5.	Future scenarios	Assumption-driven plausible and challenging descriptions of how the future state may develop based on current relevant developments.
6.	Heat Map	A matrix where vertically positioned business model components are confronted against horizontally positioned stress factors. The impact of these business scenarios on business components is expressed by colour coding.
7.	Robustness	The ability of a business model to remain feasible and viable with changing business environments.
8.	Stress factors	Formulation of future uncertainties.
9.	Viability	Relates to the financial implications of a business model, typically assessed through business cases.

Business Model Canvas

#	Term	Definition
1.	Business Model Canvas	A preformatted business model design ontology that focuses on nine business components.
2.	Cost structure	Relates to the expenses an enterprise must incur in order to sustain its business model.
3.	Customer channels	Relate to the communication, distribution and sales channels that connects an enterprise with its customers.
4.	Customer relationships	Relate to the type of personal and automated relationship an enterprise establishes with specific customer segments, typically for customer acquisition and retention.
5.	Customer segments	Relate to the different groups of organisations or individuals that enterprises must reach and serve.
6.	Key activities	Relate to the most important activities that an enterprise must focus on in order to run its business model.
7.	Key partnerships	Relate to the network of partners and suppliers that allow an enterprise to enable its business model.
8.	Key resources	Relate to the physical, intellectual, human and financial assets that an enterprise owns or leases in order operate its business model.
9.	Revenue structure	Relates to all the profit and volume streams that an enterprise generates after successfully offering its value proposition to its customers.
10.	Value proposition	Relates to the products and services that allows an enterprise to create value for its customers by solving their problems or by satisfying their needs.

Research methodology

#	Term	Definition
1.	Mixed Methods	A research methodology that involves the collection, analysis and integration of both qualitative data (e.g. through surveys) and qualitative data (e.g. through interviews).
2.	Concurrent nested mixed methods	A type of mixed methods design that provides focus on one type of method (e.g. qualitative) and then embeds the other method (e.g. quantitative) to provide broader and in-depth perspectives on the research question.
3.	Internal validity	Relates to establishing a causal relationship, where certain conditions are shown to lead to other conditions.
4.	External validity	Relates to the extent to which the results can be generalised to theoretical propositions or populations.
5.	Reliability	Relates to demonstrating the ability that the operations of a study can be repeated with the same results.
6.	Construct validity	Relates to establishing correct operational measures for the concepts that are being measured.

1 INTRODUCTION

The first chapter introduces the problem of aircraft spare part management (**1.1**), which supports the significance of the research objective to examine the impact of Blockchain as an aircraft spare part track and trace capability on the MRO business model (**1.2**). The deliverable of this chapter is a research outline that guides the reader throughout the document (**1.3**).

1.1 RESEARCH PROBLEM

According to the *International Air Transport Association* (IATA), one of the important aspects of aircraft spare part management is tracking and tracing components throughout its lifecycle (Markou & Khomenko, 2012). Every change in the movement, ownership and condition of aircraft spare parts due to modification, maintenance, lease and exchange must be reported and communicated to the *European Aviation Safety Administration* (EASA) or the *Federal Aviation Administration* (FAA) to assure airworthiness (Sahay, 2012), which is problematic and complex for the following reasons:

- Nature of aircraft configuration: Modern aircraft can contain more than a million components and unique spare part numbers (Canaday, 2017);
- Nature of spare part management: Components can be installed, removed, repaired, maintained, stored and shipped within the organisation or across the supply chain (Sahay, 2012);
- Nature of aviation supply chain: Component maintenance and logistics coordination is a challenge due to the complex, distributed, multi-stage and international nature of the aviation supply chain (Behrens, 2010);
- Nature of communication: Component data is typically shared by mail, web-based systems, storage media, paper or verbally (Global Aviation Information Network, 2003).

The main problem is that due to the complexity of aircraft spare part management and lack of Inter-Organisational Information Systems to accurately track and trace aircraft spare parts, the aviation supply chain is not deemed as transparent as desired (Sahay, 2012). Due to lack of supply chain transparency, proprietary maintenance information (e.g. component logbook data) is not made immediately available in traditional data sharing processes (Cohen & Wille, 2006). With lack of access to consistent and complete historical component records, supply chain participants (e.g. aircraft operators) face additional maintenance, communication and compliancy costs (Accenture, 2017; Li, Yan, Wang, & Xia, 2005). Component coordination capabilities are diminished, because it is difficult to fully track the history and provenance of often traded aircraft spare parts (Markou & Khomenko, 2012; IBM, 2009). When these components are not appropriately tracked and traced, there is the risk that counterfeit assets can enter the supply chain and affect aircraft safety and airworthiness (Accenture, 2018).

Research initiatives in the field of information sharing attempt to address the transparency problem by developing supporting systems and tools (Li, Yan, Wang, & Xia, 2005). *Radio Frequency Identification* (RFID) and *Internet of Things* (IoT) enabled components should improve component track and trace performance, but face limitations surrounding information synchronisation, data access and security (Ramudhin, et al., 2008; Kelepouris, Theodorou, McFarlane, Thorne, & Harrison, 2006). With evidence pointing out that Blockchain with RFID and IoT can improve supply chain transparency (Bellamy III, 2017; Tian, 2016; Korpela, Hallikas, & Dahlberg, 2017; Hua & Notland, 2016; Pflaum, Bodendorf, Prockl, & Chen, 2017; Kim & Laskowski, 2016; Kshetri, 2018), consultancies (Accenture, 2018; Lewis, 2017) and aviation industry participants (Bellamy III, 2017; Gutierrez, 2017) currently explore Blockchain as an aircraft spare part track and trace capability. Academic literature (**Appendix XVIII**) raises the importance to evaluate the impact of Blockchain on business models, especially in heavily regulated supply chains (e.g. aviation maintenance) (ECRIM, 2017; Swan, 2015; Mansfield-Devine, 2017). Even though there are clear alternatives to Blockchain (e.g. centralised databases), a decision was made to focus on Blockchain out of personal and academic interest.

1.2 RESEARCH OBJECTIVE

There is opportunity to discuss the impact of Blockchain on the robustness of the Maintenance, Repair and Overhaul (MRO) business model, since: 1) consultancy and aviation industry participants currently explore Blockchain as an aircraft spare part track and trace capability; 2) existing academic literature provides no insight how Blockchain could impact robustness of aviation business models; 3) MROs might be disrupted by the ability of Blockchain to increase supply chain and ecosystem transparency. The research objective can be formulated as:

Evaluate the robustness of MRO business models when a Blockchain consortium is established for aircraft spare part management

The first step is to engage in a desk research on aircraft spare part management and Blockchain technology in order to construct a theoretical framework. This part is dedicated to not only to capture the MRO landscape or illustrate Blockchain capabilities, but to synergise the literature in order to propose a hypothetical Blockchain use case for aircraft maintenance. This results in the formulation of the first research question:

How is Blockchain capable to track and trace the movement, modification and maintenance of aircraft spare parts and communicate it throughout the whole aviation supply chain?

The second step is to continue the desk research with focus on business model literature in order to construct an evaluation methodology that guides the research. This is done by adopting Business Model Stress Test and Business Model Canvas. This results in the formulation of the second research question:

How is it possible to systematically evaluate the robustness of MRO business models when it is confronted against Blockchain as an aircraft spare part track and trace capability?

The third step is to empirically derive the impact of Blockchain as an aircraft spare part track and trace capability on the MRO business model, which can be operationalised through increased supply chain transparency. The research collects qualitative-based interview data and quantitative-based survey data that elicit the impact evaluation of consultancy firms and industry participants. This results in the formulation of the third research question:

How does Blockchain as an aircraft spare part track and trace capability impact the MRO business model?

The fourth step is to empirically evaluate the robustness of the MRO business model by confronting it against different stress factors. Data from interviews and stress test workshop is interpreted in order to evaluate the robustness of the MRO business model through sub-view and pattern analysis. This results in the formulation of the fourth research question:

How robust are MRO business models when it is confronted against Blockchain as an aircraft spare part track and trace capability?

The fifth and final step is to empirically dive into the inter-organisational dynamics surrounding the establishment of a Blockchain consortium for the aviation industry. It is important to engage into a discussion that surpasses the scope of the MRO organisation, since a Blockchain consortium is only feasible when it is supported by industry participants and regulatory institutions. This results in in the formulation of the fifth research question:

How feasible is it for the aviation industry to consider a Blockchain consortium for the purpose of aircraft spare part management?

1.3 Research outline

The research outline guides the reader throughout the seven chapters of this research by highlighting the content and outcome of each chapter. A summary of the outline is captured in a figure on the next page (**Figure 1**).

Chapter 1 – Introduction: The first chapter introduces the problem of aircraft spare part management (**1.1**), which supports the significance of the research objective to examine the impact of Blockchain as an aircraft spare part track and trace capability on the MRO business model (**1.2**). The deliverable of this chapter is a research outline that guides the reader throughout the document (**1.3**).

Chapter 2 – Theoretical framework: The second chapter engages in a desk research to provide theoretical background on aircraft spare part management (**2.1**) and Blockchain technology (**2.2**). The deliverable of this chapter is a design synthesis that discusses how Blockchain can track and trace aircraft spare parts (**2.3**). This chapter concludes by reflecting on the first research question (**2.4**).

Chapter 3 – Evaluation methodology: The third chapter engages in a desk research on business models to introduce Business Model Stress Test (**3.1**). This methodology is used to formulate and empirically validate a literature-based MRO Business Model Canvas (**3.2**) and stress factors against which the MRO business model will be confronted (**3.3**). The deliverable of this chapter is an evaluation methodology that presents the MRO Business Model Canvas and how it can be evaluated. This chapter concludes by reflecting on the second research question (**3.4**).

Chapter 4 – Evaluation methodology: The fourth chapter is dedicated to support the replicability of the research and guide any prospect researcher by first introducing the conceptual model (**4.1**), discussing the mixed methods approach (**4.2**), formulating the research strategy (**4.3**) and reflect on research validity and reliability (**4.4**). Given the purpose of this chapter to support research replicability, it does not address any research questions.

Chapter 5 – Results: The fifth chapter presents the qualitative interview and quantitative survey results from sixteen interviews in a consistent logical sequence. The first part of the results focused on the impact of Blockchain as an aircraft spare part track and trace capability on the MRO business model (**5.1**). The second part of the results focuses on evaluating the robustness of the MRO business model (**5.2**). An additional third part of the results focuses on the feasibility of the Aviation Blockchain consortium, which is considered important by the interview participants (**5.3**).

Chapter 6 – Conclusion: The sixth chapter first addresses the five research questions proposed in the first chapter of the thesis (**6.1**). Based on these conclusions, the chapter then discusses the research problem, research objective and Blockchain limitations (**6.2**). The deliverable of this chapter are managerial recommendations that prepare MROs for Blockchain and academic recommendations for future research (**6.3**).

Chapter 7 – Discussion: The seventh and final chapter of this thesis reflects upon the strengths and limitations of the research (**7.1**); the managerial (**7.2**) and academic relevance of the research (**7.3**); the relationship of this research with Management of Technology (**7.4**).

Appendix book: A separate document is created to include the research appendices. The appendices include: 1) interview transcripts (**Appendix I – XVI**); 2) heat map justification (**Appendix XVII**); 3) Literature review justification (**Appendix XVIII**).

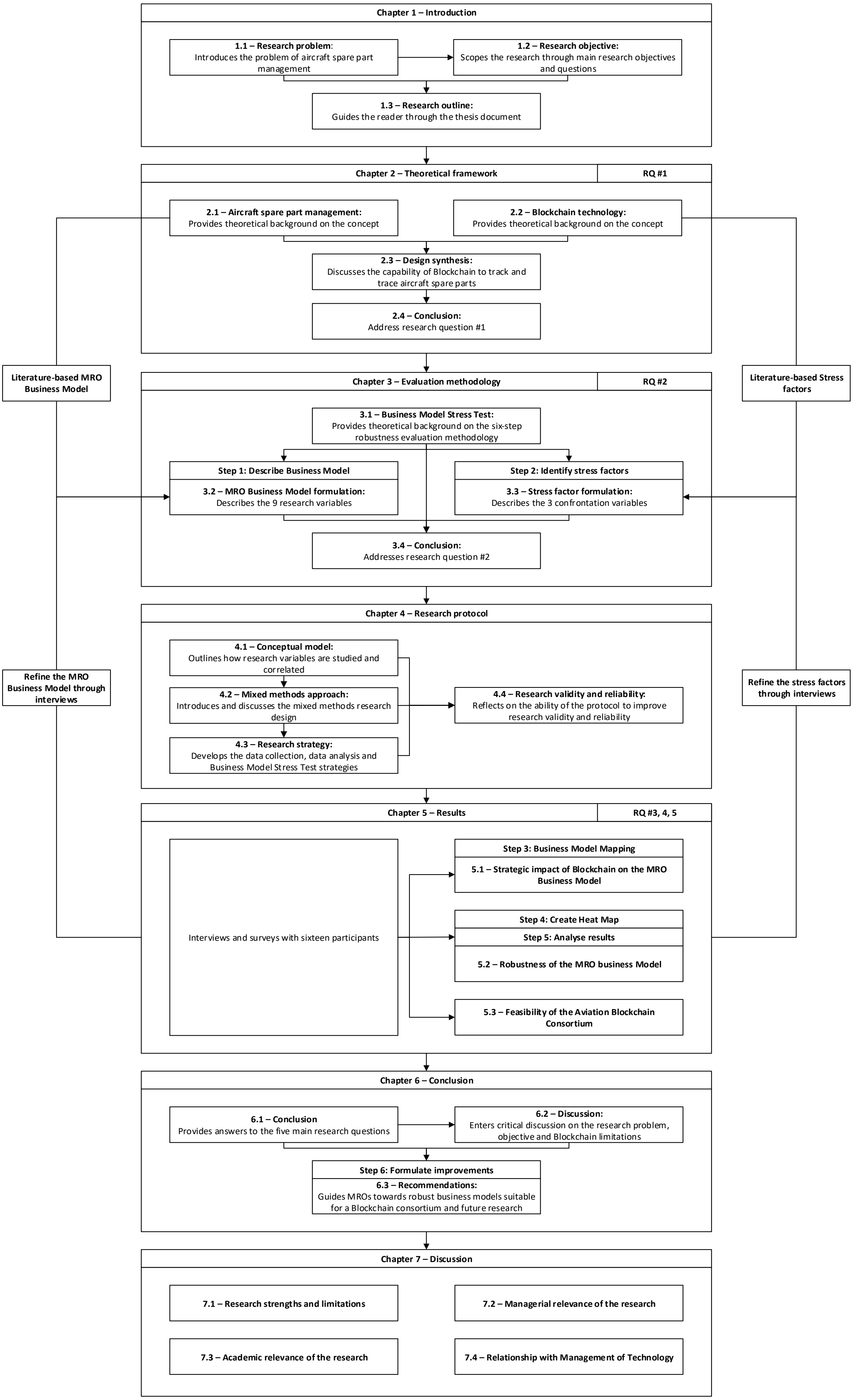

Figure 1 – Research outline

2 Theoretical framework

The second chapter is dedicated to highlight how Blockchain can be used for aircraft spare part management. The chapter first engages in a desk research to provide theoretical background on aircraft spare part management (**2.1**) and Blockchain technology (**2.2**). These paragraphs both provide theoretical background and then delve into its ecosystem, given the importance to understand the interdependencies between aviation industry participants and how this could change in a Blockchain environment. The literature review supporting this chapter is included in the appendix, which segments the literature and its general insight into key groups (**Appendix XVIII**). The deliverable of this chapter is a design synthesis that discusses how Blockchain can track and trace aircraft spare parts (**2.3**). This chapter concludes by reflecting on the first research question (**2.4**):

How is Blockchain capable to track and trace the movement, modification and maintenance of aircraft spare parts and communicate it throughout the whole aviation supply chain?

2.1 Aircraft spare part management

This paragraph provides theoretical background on the concept of aircraft spare part management with focus on its fundamentals (**2.1.1**) and ecosystem (**2.1.2**).

2.1.1 Aircraft spare part management fundamentals

The first part delves into the fundamentals of aircraft spare part management: 1) introduction to aircraft spare part management (maintenance strategies, types of components); 2) complexity of aircraft spare part management; 3) strategic importance of track and tracing components; 4) solutions for tracking and tracing components; 5) and their limitations.

Introduction to aircraft spare part management

When legal evidence exists that any aircraft (e.g. helicopters, balloons, commercial aircraft) complies with predetermined regulation standards, it will receive a Certificate of Airworthiness that is signed and published by an authorised representative of the national aviation authorities (Sahay, 2012). When an aircraft loses its legal *airworthiness* status, it enters the maintenance process with the purpose to ensure and restore aircraft safety and reliability at a minimum total cost. These processes follow a certain maintenance strategy that determine how and which aircraft spare part is replaced or maintained (Mostafa, Lee, Dumrak, & Chileshe, 2015). A distinction is made between three primary maintenance strategies, based on the timeframe of spare part failure detection and type of failure (**Figure 2**):

- Design-Out Maintenance: Dedicated to improve the design of the spare part in order to minimise or eliminate the cause of maintenance.
- Preventive Maintenance: Dedicated to reduce the probability of failure occurrence by engaging in condition-based predictive maintenance or periodic maintenance.
- Corrective maintenance: Dedicated to immediately engage in maintenance after failure detection or deter it, which is assessed by qualified technicians.

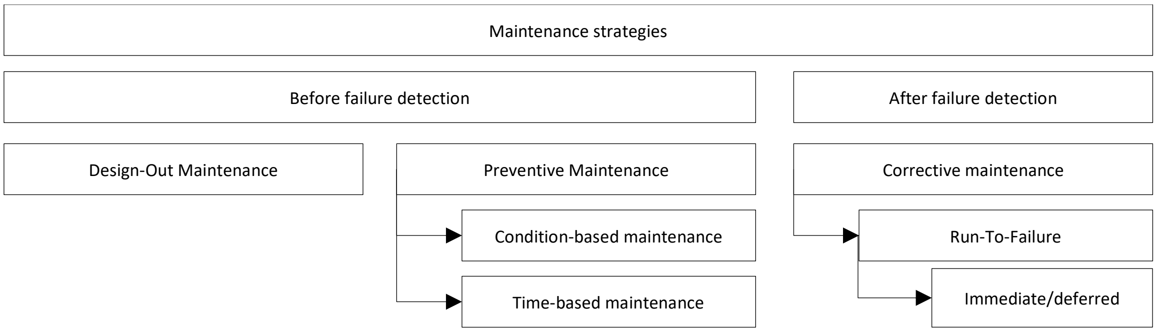

Figure 2 – Aircraft maintenance strategy classification (Mostafa, Lee, Dumrak, & Chileshe, 2015)

Aircraft spare part management is considered one of the most important aircraft maintenance operations, because it is necessary to adequately manage aircraft and engine inventories to assure that spare parts are available at the lowest costs for aircraft maintenance and prevent spare part related flight delays and cancellations (IATA, 2015). These *aircraft spare parts* differ in its scrap rate, financial classification, lifecycle and tracking considerations (**Figure 3**):

- Rotable aircraft spare parts (SPC 2): Large subsystems with negligible scrap rates (e.g. wheels, brakes) that can economically be restored to serviceable condition by moving through the same repair and overhaul process many times throughout its lifecycle.
- Repairable aircraft spare part (SPC 6): Compared to rotables, these components (e.g. oxygen bottles, fire detector, Auxiliary Power Unit starter) are more limited in their durability and more often replaced throughout its lifecycle due to its higher scrap rate.
- Expendable aircraft spare parts (SPC 1): Inventories (e.g. lamps, filters, fasteners) with 100% scrap rates that is discarded and replaced upon its removal.
- Recoverable aircraft spare parts: Throw-away expendable items that are treated as repairables by repairing them through approved reconditioning process.
- Limited Life Parts: Engine specific parts (e.g. High-Pressure turbine rotor disk) that is subject to hour or lifecycle restrictions and are destroyed at the end of its lifecycle.

	Aircraft inventory				
	Airframe/Engine inventory				Engine inventory
Type	Rotables	Repairables	Expendables	Recoverables	Limited Life Parts
Scrap	Negligible	Between 0% and 100%	100%, one-time use	Very high	100%, destroyed after use
Financial	Asset held on firm book	Asset held on firm book	Consumable expensed at use	Classified as a repairable	Asset held on firm book
Lifecycle	Indefinite	Persist until scrap	Consumed at time of use	Persist until scrap	Subject on hour or lifecycle restrictions
Tracking	Yes – SPC 2	Yes – SPC 6	Yes – SPC 1	Unknown	Yes – based on lifecycle
Examples	Wheels, brakes, flaps	Oxygen bottles, fire detector	Lamps, filters, seals, fasteners	High scrap rate repairables	High-Pressure Turbine rotor

Figure 3 – Aircraft spare part inventory classification (IATA, 2015)

Complexity and importance of tracking and tracing aircraft spare parts

According to IATA, one of the important aspects of aircraft spare part management is tracking and tracing aircraft spare parts internally throughout the MRO organisation and externally across the entire aviation supply chain (Markou & Khomenko, 2012). *Tracking* relates to determining the current state of an aircraft spare part, whereas *tracing* involves determining its historical state and origin using traceability data. This *traceability data* includes information on part location, ownership, maintenance and usage history. In comparison to other industrial supply chains, such as the food or pharmaceutical supply chain, aircraft spare parts must be tracked and traced even after the aircraft is manufactured and delivered. Throughout its lifecycle, the traceability data is recorded and exchanged between various participants of the international, complex aviation supply chain. However, the problem is that it is difficult to appropriately manage this data, since modern aircraft can contain more than a million components and unique spare part numbers, typically in multiple quantities per aircraft (IATA, 2015). The complexity of tracking and tracing is increased when components, such as aircraft rotables and engine Limited Life Parts, are installed, removed, repaired, maintained, stored and shipped within the MRO or across the supply chain. Every change in the movement, ownership and condition of aircraft spare parts as a result of modification, maintenance, lease and exchange must be reported and communicated to assure airworthiness (Sahay, 2012).

Strategic importance of tracking and tracing aircraft spare parts

The importance of inter-organisational information sharing practices is extensively studied and discussed throughout academic literature. Effective information sharing and coordination capabilities can improve supply chain agility, as supply chain participants reduce information asymmetry and improve their decision-making processes (Kumar & Pugazhendhi, 2012). Not only is it possible to identify the relationship between information sharing and supply chain performance, it is also possible to identify its relationship with organisational performance (**Figure 4**) (Baihaqi & Sohal, 2013). With data from 150 companies, Baihaqi & Sohal identified the impact of information technology and information quality on the intensity of information sharing. However, it concludes that this intensity does not directly correlate with organisational performance, as it is mediated by supply chain collaboration strategies. It shows that information sharing is essential, yet insufficient to achieve performance improvements.

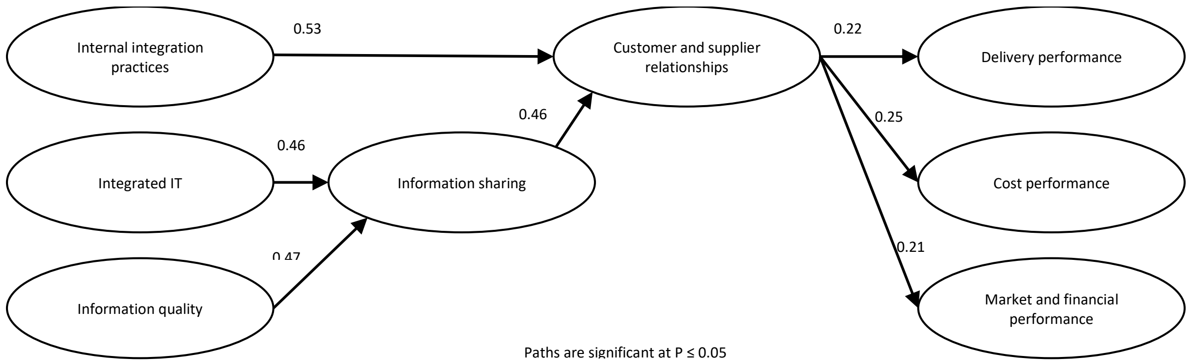

Figure 4 – Impact of information sharing on organisation performance (Baihaqi & Sohal, 2013, p. 750)

Research on information sharing in various circumstances and assumptions draw conclusions on how information sharing should be evaluated (Baihaqi & Beaumont, 2006). Any study on information sharing should understand the notion that the value and benefits of information sharing might vary among supply chain participants. Therefore, evaluation of existing information sharing practices requires the identification of: 1) the content of information that is shared; 2) the participants with whom the information is shared; 3) the process of how the information is shared; 4) the user and system requirements for tracking and tracing solutions.

Within the context of tracking and tracing aircraft spare parts, the importance of information sharing means that it is important to appropriately share high-quality traceability data throughout the aviation supply chain and exploit this in decision-making processes. The performance of aircraft spare part tracking and tracing practices is related to information quality (Kelepouris, Theodorou, McFarlane, Thorne, & Harrison, 2006). Kelepouris et al engaged in a literature review to identify quality metrics (Lee, Strong, Kahn, & Wang, 2002):

- Completeness: Degree to which aircraft spare part documentation and data is shared without discrepancies. Newer technologies enable complete data provision by capturing and propagating complete sets of data on: 1) present and historical part ownership and location; 2) part condition regarding its quality, reliability and maintenance history; 3) environmental and operational conditions to which the item is subject to throughout its lifecycle; 4) potential tampering attempts.
- Timeliness: Degree to which aircraft spare part documentation and data is shared in real-time. Newer technologies enable high speed data provision by reducing manual effort to automate data capturing processes. This allows items to be communicated in real-time, reducing any communication delay through the supply chain.
- Accuracy: Degree to which aircraft spare part documentation and data is shared in detail. Newer technologies enable accurate data provision by reducing manual effort to eliminate human errors. This allows sophisticated and detailed provision of item identification, location and time throughout the supply chain.

Kelepouris et al discuss the usage of RFID tags as a means to improve tracking and tracing performance and create value for the aviation supply chain (Kelepouris, Theodorou, McFarlane, Thorne, & Harrison, 2006). Enterprises can exploit competitive advantage from RFID by reducing costs (Ngai, Cheung, Lam, & Ng, 2014), through increased supply chain efficiencies (Tajima, 2007), and by combining it with IoT to log the asset lifecycle (Abdel-Basset, Gunasekaran, & Mohamed, 2018). The premise of real-time, accurate and complete aircraft spare part location, ownership and condition tracking and tracing shows the benefits for MROs, which includes (Kelepouris, Theodorou, McFarlane, Thorne, & Harrison, 2006):

- Operational benefits: Increased inventory accuracy; optimised order and inventory processes; reduced Mean-Time-To-Repair; Reduced costs and time for unnecessary part replacement; product recall cost reduction; increased tool capacity utilisation; automated warranty claim processing; document tracking.
- Legislative benefits: Reduced costs from fines, since they can trace components with complete and accurate data.
- Safety and risks benefits: Reduced counterfeit products when components are tracked and traced.

Solutions for tracking and tracing aircraft spare parts

Various RFID based solutions have been designed and implemented to meet the disperse business requirements of the aviation supply chain participants (Kelepouris, Theodorou, McFarlane, Thorne, & Harrison, 2006). These can be categorised in seven key applications with their own examples that overlap in functionality:

- Point-To-Point reusable asset tracking: These solutions record the position of reusable assets that is transferred within maintenance and manufacturing or throughout the supply chain.
    - Savi’s Shared RFID-based Network: Allows shippers, logistics service providers and transportation companies to track and trace containerized ocean cargo.
- Real time asset tracking: These solutions estimate the position of an asset within an area in real time
    - General Electric Engine Assembly Tracking System: Facilitates GE with real-time precision tracking of engines, equipment and kits in multi-path environments.
- Full traceability and product authenticity: These solutions ensure full traceability and authenticity by providing details on each asset
    - Drug Security Network: Used by major pharmaceutical players to provide a complete, traceable chain of custody of products.
- Tool tracking and tracing: These solutions track and trace reusable assets that is shared between engineers in the same or different companies.
    - Airbus Tracking Tools: Airbus equipped RFID in all their tools and toolboxes, which allow tool movement and condition tracking.
- Documentation tracking: These solutions track documentation (e.g. aircraft readiness log) that accompany aircraft and engine spare parts
    - Boeing RFID pilot: Boeing tested a passive system for tracking Work-in-progress equipment by attaching RFID tags to documents that travel with parts.
- People tracking and tracing: These solutions ensure that only authorised personnel with the correct training can access areas or use equipment
    - BP trial: BP trialled a people tracking and tracing system by ensuring only RFID equipped personnel can access safety equipment and conduct operations.
- Baggage, air cargo and reusable asset tracking: These solutions identify baggage, air cargo and reusable assets along its supply chain.
    - ELSG SkyChef’s trolley tracking: The first solution that offers airlines the ability to track catering trolleys through the airlines global catering network.

Challenges of tracking and tracing aircraft spare parts

Ramudhin et al recommends to continue developing new RFID solutions and frameworks that support high quality information exchange between supply chain participants. Deploying any track and trace performance enhancing technologies within MRO processes requires consideration of a few key research challenges (Ramudhin, et al., 2008; Kelepouris, Theodorou, McFarlane, Thorne, & Harrison, 2006; Ngai, Cheung, Lam, & Ng, 2014):

- On-chip information: It is necessary to develop an information strategy that identifies which information is stored and how it is communicated. This requires an analysis of the requirements of all supply chain participants.
- Information synchronisation: It is necessary to ensure that information must be communicated effectively and efficiently with enterprise information systems across the supply chain. This requires an evaluation of existing legacy systems and databases.
- Documentation tracking: It is necessary to evaluate how aircraft spare part related documents could be tracked and traced throughout the supply chain. This requires an evaluation of which information is carried by the documents and when it is read.
- Security and data access rules: It is necessary to ensure that information is not subject to manipulation. This requires allocation of security permissions throughout the supply chain, because not all participants must have the same reading and editing rights.
- Information sharing and data access security issues: As one of the most important challenges of aircraft spare part tracking and tracing, it is necessary to enhance information visibility throughout the whole supply chain. This requires an architecture that enables information exchange, with important consideration of scalability, security concerns, data standards and general network architecture (e.g. centralised or decentralised database).

2.1.2 Aircraft spare part management ecosystem

The second part delves into the ecosystem of aircraft spare part management and the dynamics of inter-organisational information and asset transactions with focus on its: 1) content; 2) participants; 3) process; 4) requirements.

Content of inter-organisational information and asset transactions

Since the movement, exchange and maintenance of aircraft spare parts must be recorded and communicated throughout its lifecycle, it is necessary to establish a communication protocol that captures which information must be shared during any transactions that significantly affects the condition or ownership of the aircraft spare part. This communication is streamlined by *Spec 2000*, a Business-to-Business communication and data exchange standard proposed by IATA (Air Transport Association, 2004).

Throughout its lifecycle, an aircraft spare part is identified with an enterprise identifier and a unique serial number. The enterprise identifier is either the Manufacturer's Code (MFR) for new spare parts or the Supplier's Code (SPL) for spare parts that were in service when tagging took place, which is denoted as five-character Commercial and Government Entity (CAGE) codes. Additionally, owners of the spare parts must assure that the component is unique within the enterprise by assigning a Part Serial Number (SER) or Unique Component Identification Number (UCN). Information related to the MFR, SPL, SER for new parts, UCN for in-service parts must be marked once and never change to effectively track and trace a component throughout its lifecycle. What can change throughout the component lifecycle is the Part Number (PNR) when the owner (ACO) at a certain date (ACD) engages in an action (ACT) that affects the component. Various approved industry action codes must be tracked throughout the component lifecycle, which must also highlight whether the component is in serviceable (SRV) or unserviceable (UNS) condition (**Table 1**).

Table 1 – Approved industry action codes that must be tracked (Andresen, 2005)

MRK	Marked unit	RMV	Removed from	SLD	Sold to	OTH	Other
MFG	Manufactured	RPR	Repaired	BUY	Bought from	RCD	Received from
SHP	Shipped to	OVH	Overhauled	SCP	Scrapped	UPG	Upgraded PNR
INS	Installed on/in	EXC	Exchanged with	WHR	Warehoused	INP	Inspected

Any supply chain participant that engages in a transaction to exchange an aircraft spare part must provide data on minimum Spec 2000 requirements in order to reconstruct the historical origin of its part. Not only does Spec 2000 provide minimum traceability data requirements, it provides also recommendations on information that should be shared, and information that might be worth tracking and tracing (**Table 2**).

Table 2 – Spec 2000 traceability data (Air Transport Association, 2004)

Minimum	Recommended	Additional
CAGE Code (MFR/SPL)	Aircraft status change	Product attributes
Part Serial Number (SER/UCN)	Aircraft general statistics	Safety information
Current Part Number (PNR)	Component removal/installation	Operational history
Action company (ACO)	Aircraft logbook	Transportation/Storage
Action Date (ACD)	Scheduled maintenance	
Action Code (ACT)	Component shop repair	
	Service Bulletin	

An example is included to visualise how this information may be interpreted by the traceability database, which at least contains information on the CAGE code, part serial number, current part number, action, date of action, and company that engaged on the action. Additionally, information on the part OEM, original part number, aircraft designation number, condition and internal location could be included (**Table 3**).

Table 3 – Traceability database example (Andresen, 2005)

Minimum traceability standard						Optional information				
CAGE	**SER**	**PNR**	**ACT**	**ACD**	**ACO**	**OEM**	**ORG PNR**	**CAN**	**COND**	**INT LOC**
61G49	1234567	P7DTR26	RMV	23/11/99	83PH4	Collins	T52D611	UA3482	UNS	Shop 141
91673	83H6290	459873L8	INS	23/11/99	83PH4	Collins	83H6290	UA3482	SRV	UA3482
91673	SS12932	9J9846	SCP	24/11/99	83PH4	Honeywell	H12933		UNS	

Participants of inter-organisational information and asset transactions

The overall lifecycle of an aircraft spare parts relates to all phases from development until its disposure (**Figure 5**): 1) design and build where the spare parts are manufactured and certified; 2) sales and delivery where the spare parts are accepted by an aircraft operator; 3) technical documentation and inspection log where OEM documentation is created for the spare parts and sent to the operator; 4) manage configuration where the spare part is phased-in and provisioned; 5) plan, execute and certify maintenance work where the operator assures airworthiness; 6) manage handover where the spare part is phased-out. Through the entire lifecycle, these spare parts are identified, tracked and traced, typically with RFID (Sahay, 2012).

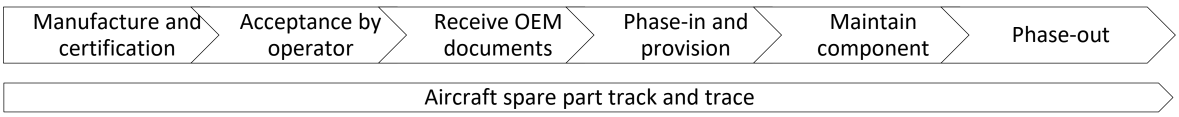

Figure 5 – Aircraft spare part lifecycle process (Sahay, 2012)

It is a challenge to map out all the relevant parties that are interested in the traceability data of aircraft spare parts, since it involves both parties that exchange the assets and parties that oversee these transactions for legislative purposes. Currently, there is ambiguity regarding which parties are part of such an ecosystem, which is why it is necessary to review existing literature on MRO operations to deduct which parties fulfil which role.

Based on a review of existing literature on aircraft spare part tracking and tracing, it is possible to identify three key parties that are part of the aircraft spare part ecosystem. This can be captured in an aircraft spare part supply chain reference model that highlights the primary relationships between the parties (MacDonnell & Clegg, 2006):

- Aircraft operator: Entities that provide pre-flight and onboard services, with the primary purpose to maximise aircraft utilisation. When an aircraft or its component is deemed unserviceable, it is sent to MRO providers.
- *Maintenance, Repair and Overhaul provider* (MRO): Entities that are responsible for maintaining, repairing, inspecting and modifying unserviceable aircraft, engine and components to secure airworthiness and provide serviceable components.
- *Original Equipment Manufacturer* (OEM): Entities that are responsible for manufacturing aircraft (e.g. Boeing), engines (e.g. General Electric) and components (e.g. Honeywell) for MRO providers.

It is possible to extend this model with information flows between the key parties and the Spec 2000 database (Air Transport Association, 2000). MRO, OEM and operators have access to spare part related information with an internet browser, a mainframe application and *Enterprise Resource Planning* (ERP), such as SAP. Through the internet, SITA/ARINC Class B mainframe or through physical media updates, it is possible for these applications to communicate and synchronise with the Spec 2000 centralised database. The database is protected by a security and authentication filter that ensures that only users with appropriate viewing rights can access it. This discussion can be captured in an aircraft maintenance supply chain reference model that capture all relevant parties and its information flows (**Figure 6**).

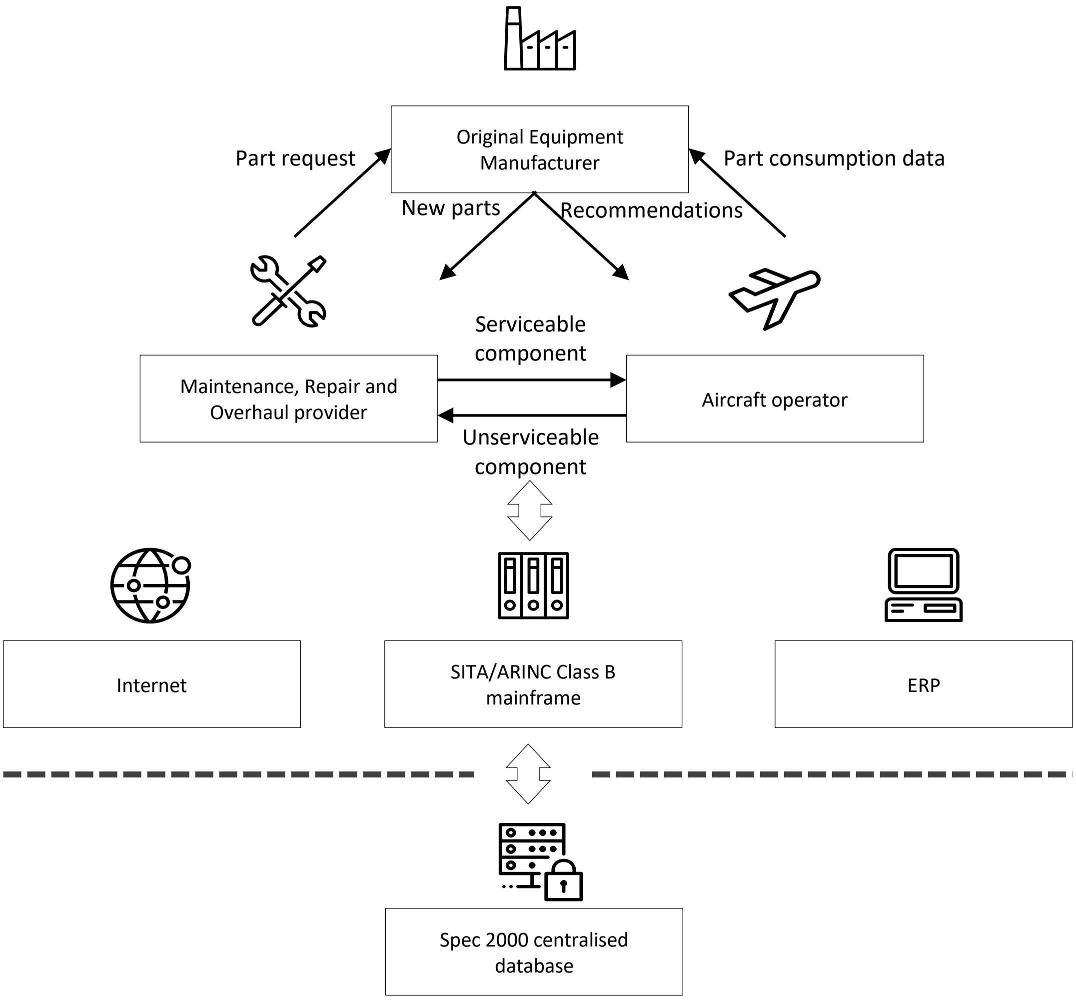

Figure 6 – Aircraft spare part ecosystem (MacDonnell & Clegg, 2006; Air Transport Association, 2000; Cohen & Wille, 2006)

However, the ecosystem is much more complex, as it involves entities beyond OEMs, MROs and aircraft operators with whom these components can be exchanged (e.g. external repair vendor, parts trader). Additionally, during these transactions, the components pass through various intermediaries that ensure that the components arrive at their destination (e.g. distributors, logistics, customs). Furthermore, regulatory entities oversee these transactions to ensure that each change in the movement, ownership and condition of the spare parts are reported and communicated in order to assure airworthiness (e.g. EASA, FAA).

Process of inter-organisational information and asset transactions

An example of the MRO business process map provides extensive insight into the interaction between aircraft operators and MRO providers, where unserviceable components are maintained to serviceable condition. This process visually demonstrates how aircraft spare part and information flows are present between the aircraft operator and the MRO provider (Palma-Mendoza & Neailey, 2015). In this process, the spare parts are physically exchanged between the airline, logistics, external and internal repair shops. However, information is exchanged between the airline, component control, customer services, logistics, and repair services (**Figure 7**). Throughout this process, any significant action or exchange related to the aircraft spare part is reported in the ERP system for regulatory purposes. In a typical workflow, it is necessary to consult traceability data in order to continue the repair process (e.g. inform sales when there is part and serial number discrepancy; generate serial numbers and send parts to quality assurance for verification) (Lee, Ma, Thimm, & Verstraeten, 2008).

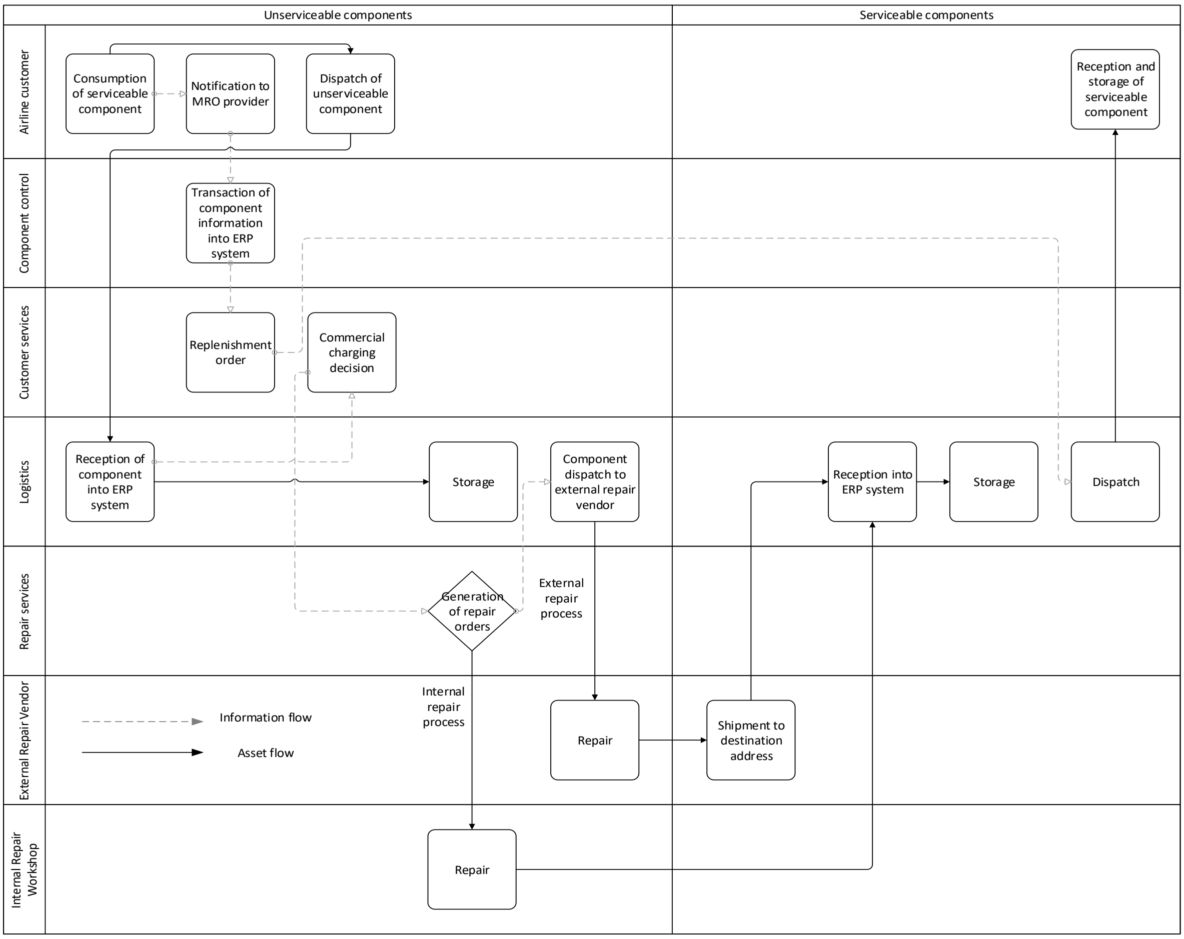

Figure 7 – MRO business process map (Palma-Mendoza & Neailey, 2015, p. 19)

Requirements of inter-organisational information and asset transaction

When considering a track and trace solution, it is important to evaluate whether this solution conforms with predefined contextual factors. To map these constraints, it is necessary to dive into literature to specify industry and system requirements to track and trace aircraft spare parts (Kelepouris, Theodorou, McFarlane, Thorne, & Harrison, 2006). Industry requirements to achieve the goal of track and trace performance optimisation include: item identification, document and asset tracking, automatic information capture and system update, complete part information, and automatic electronic certificate generation. The issue tree shows why it is important to improve track and trace performance, as it is possible to identify underlying problems that affect organisational performance (**Figure 8**).

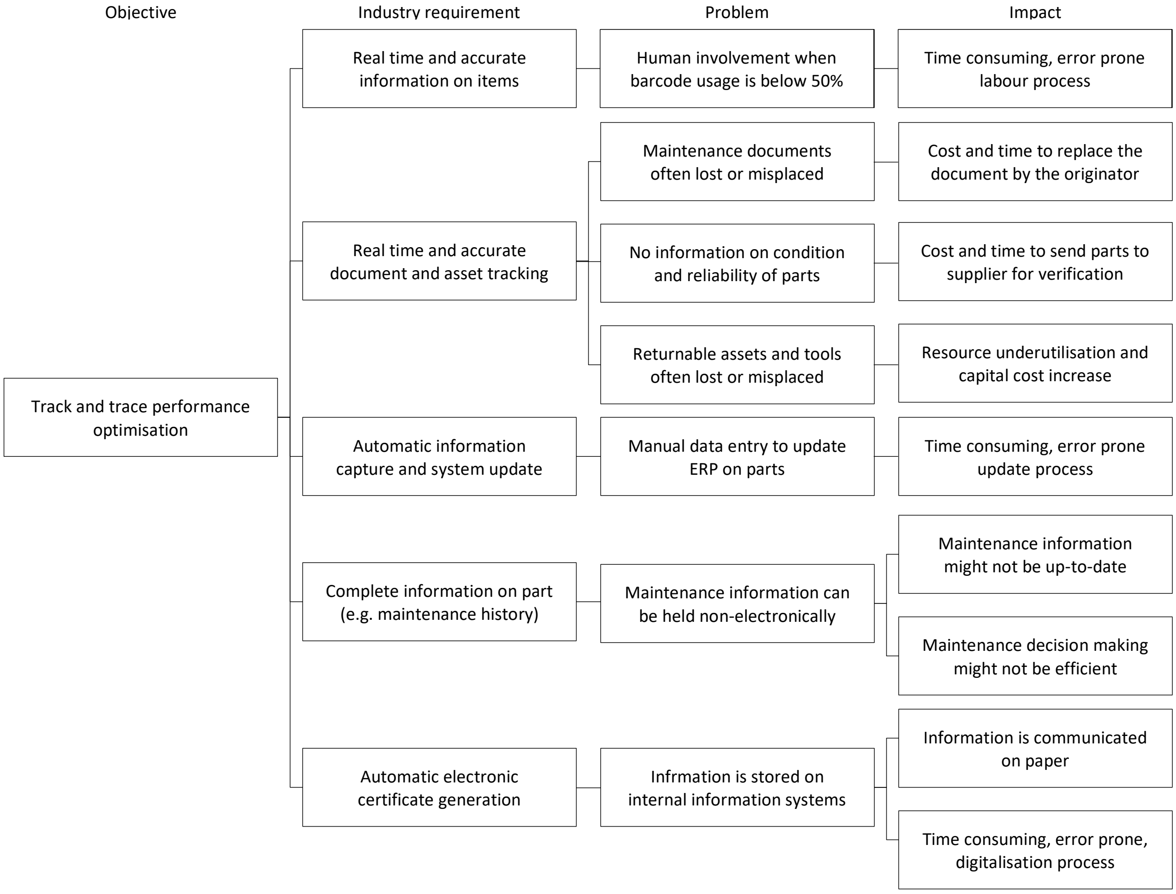

Figure 8 – Industry requirements (Kelepouris, Theodorou, McFarlane, Thorne, & Harrison, 2006)

The system requirements relate to the importance to meet industry requirements, which include:

- Business drivers: Legislative drivers to meet minimum traceability standards and operational drivers to optimise business processes and reduce costs.
- Application characteristics: Designing frameworks and applications to ensure that accurate, real time and complete information can be used to improve decision making.
- Information management: Aligning legacy IT infrastructures with the new technology and ensuring information visibility by adopting a standard communication method.
- Data processing: Developing a network that captures and updates data on any time, with critical focus on data synchronisation between disperse locations.
- Functional requirements: Ensuring that the capability does not interfere with aircraft equipment and meet airworthiness criteria.
- Numbering standards: Consistently presenting the part traceability data to comply with Spec 2000 directives.

2.2 BLOCKCHAIN TECHNOLOGY

This paragraph provides theoretical background on the concept of Blockchain technology with focus on its fundamentals (**2.2.1**) and ecosystem (**2.2.2**).

2.2.1 Blockchain fundamentals

The first part delves into the fundamentals of Blockchain technology: 1) introduction to Blockchain technology (origin of the concept, Bitcoin protocol); 2) emergence of smart contracts (Ethereum protocol); 3) interpretation of the concept; 4) review on Blockchain as a track and trace capability; 5) limitations and risks of the technology.

Introduction to Blockchain technology

The foundation underlying Blockchain technology can be traced back to 1991, when digitalisation of text, audio and video created the need to authenticate the documents with time-stamp certification. The one-way *hash function* is proposed as a mathematical, computational algorithm that processes binary strings of arbitrary length to binary strings of fixed length that acts as the digital fingerprint of the document. Due to the cryptographic properties of this solution it is impossible to reconstruct the input data by only knowing the hash value, which assures the integrity and authenticity of the data (Haber & Stornetta, 1991).

Around 2008, an unknown entity or person known as Satoshi Nakamoto introduced the *Bitcoin protocol*, which is a peer-to-peer timestamp server that relies on cryptographic hash functions rather than trust to computationally register and confirm electronic transactions without intermediaries (Nakamoto, 2008). Bitcoin solves the double-spending problem by chronologically keeping a distributed ledger that verifies that the currency used for one transaction is not already used for another transaction. The ledger is maintained and verified by a network of nodes rather than a trusted third party or central authority. This distributed ledger is known as the Blockchain, where each block includes a set of transactions that are linked with previous blocks through cryptographic hashes (**Figure 9**).

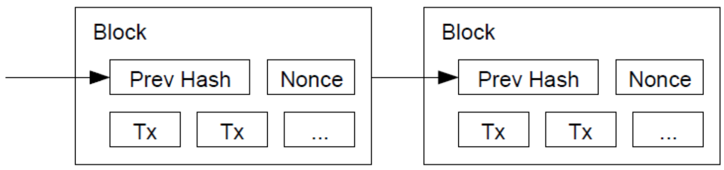

Figure 9 – Blockchain architecture (Nakamoto, 2008, p. 3)

Once a set of transactions form a block and receive a hash, it is taken by the timestamp server and broadcasted to all nodes of the network (**Figure 10**). The network of nodes must reach consensus through Proof-of-Work by using its CPU to computationally solve a cryptographic puzzle, which is a process known as mining. In this case, the first miner to solve the cryptographic puzzle receives incentives in form of Bitcoin. Before reaching consensus, the nodes always consider the hash values of the longest chains, which is possible because each node contains a copy of the Blockchain and its historical record of all valid transactions in chronological order. Once the network reaches consensus, the new block is added to the preceding chain of blocks.

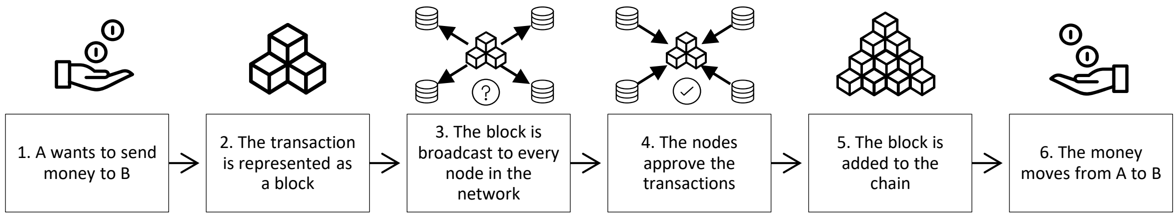

Figure 10 – Financial transactions through Blockchain (Nakamoto, 2008)

Emergence of smart contract and properties

The next tier in Blockchain development was solidified by the emergence of the *Ethereum protocol*, which is a Blockchain-based computing platform with a Turing-complete programming language that enables smart contracts (Buterin, 2013). *Smart contracts* are business rules that are embedded in computer-code and programmes that are then cryptographically computed on the Blockchain to provide autonomy, self-sufficiency and decentralisation to a degree that is not offered by traditional contract law or third parties. These smart contracts use its code to automatically validate whether pre-specified conditions have been met and then execute or enforce the appropriate action or transaction (Swan, 2015; Szabo, 1994; Walport, 2016). The smart contract concept can be extended to establish Decentralised Autonomous Organisations, which encode all assets and rules of an organisation through long-term smart contracts (Buterin, 2013).

Given the cryptographic properties of the Blockchain, it is possible to hash both tangible (e.g. vehicles, real-estate, electronics) and intangible assets (e.g. copyrights, commodities, certifications). By hashing these *smart properties* with a unique identifier on the Blockchain, it is possible to track, control and exchange its ownership. These records cannot be changed and can be audited by anyone, which can prevent fraud and loss of integrity. An example is transferring car ownership from a dealer to an individual owner, who then has access to the private key of that car. In such cases, smart contracts can also be used to automatically transfer car ownership when the Blockchain-based smart contract verifies that the individual owner paid all its loans. This concept can be extended with embedded technologies (e.g. iBeacons, Wi-Fi, sensors, QR Codes, NFC tags, IoT) to literarily control physical assets with the Blockchain. For example, it would be possible for the Blockchain to open the door of a car by using QR codes and smart contracts (Swan, 2015; Szabo, 1994; Walport, 2016; Buterin, 2013).

Interpretation of the Blockchain concept

Scientific literature recognises that distributed database systems are rendered useless if it does not consist of specific elements that promote decentralisation and improved business economics (Özsu & Valduriez, 1991). According to this body of literature, distributed database systems must (Tanenbaum & van Steen, 2001): 1) improve remote data and resource accessibility; 2) improve transparency by accurately and consistently reducing differences in data presentation; 3) promote openness by adhering to standardisation of system semantics; 4) facilitate system scalability in terms of size, geographic distance and administration. Given the design of Blockchain to adopt a cryptographic distributed database structure (Nakamoto, 2008), it is understandable how the core principles of distributed database systems are translated into the previously discussed Blockchain key elements (Garzik & Donnelly, 2018)

The development and deployment of Blockchain can be divided in three tiers (Swan, 2015): 1) Blockchain 1.0 relates to the deployment of Blockchain-based currencies (e.g. Bitcoin) and cash transfer applications; 2) Blockchain 2.0 relates to the deployment of Blockchain-based contracts (e.g. Ethereum) that go beyond cash transfer applications (e.g. smart contracts and smart properties) (Buterin, 2013); 3) Blockchain 3.0 relates to Blockchain applications beyond currency and finances (e.g. field of governance and science). An attempt was made to categorically enumerate the wide spectrum of assets that can be registered through the Blockchain (Swan, 2015): 1) financial instruments, records and models (e.g. currency, equities, bonds); 2) public records (e.g. land titles, licenses); 3) private records (e.g. signatures, wills, trusts); 4) semi-public records (e.g. degree, certifications, GPS trails); 5) physical asset keys (e.g. home key, car key, safety deposit keys); 6) Intangibles (e.g. coupons, tickets, patents).

From a technical, business and legal perspective, *Blockchain technology* is respectively 1) a cryptographic distributed ledger database that 2) facilitates the transaction of value between network participants and 3) validates the transactions with consensus mechanisms that remove the need of intermediaries (Mougayar, 2016).

To remove ambiguity that is present in existing Blockchain literature, it is it is necessary to adopt a scientific interpretation that defines the essence of Blockchain in nine key elements (Garzik & Donnelly, 2018):

- Trust shifting: Trust was placed on intermediaries, which results in counterparty risk and increased costs. With the Blockchain, trust moves towards its cryptographic system. The strength of the system depends on the power of the network.
- Decentralisation: The absence of centralised authorities that normally decide the rules or dictate the decision-making process is replaced by distributed nodes.
- Machine-to-Machine Automation: With Blockchain and smart contracts, it is possible to enable machine-to-machine communication without further human intervention.
- Cryptography: With the presence of a Public/Private-Key infrastructure and underlying cryptography technology, the Blockchain is both transparent and secure.
- Permission: Depending on the purpose and design of the Blockchain, it is possible for any individual to participate in the Blockchain network without prior invitation. In specific business contexts, it is necessary to adopt a permissioned Blockchain system.
- Validity: Validating the Blockchain is a continuous process that verifies previous transactions that are included in the new block, thus increasing the historical strength of the Blockchain.
- Immutability: Once data is written on the Blockchain it cannot be modified by anyone, since it requires the support of the whole network to revert historical data.
- Uniqueness: The double spend problem is solved, because the Blockchain architecture prevents the same asset from being sent to different parties.
- Authentication: All data that is recorded on the Blockchain can be both audited and authenticated, which ensures that the Blockchain is capable to support real-time track and tracing opportunities. The Blockchain serves as one central place where it is possible to determine the ownership of an asset or the completion of a transaction.

The Blockchain architecture can be summarised in a framework of three layers that was also used to portray the Internet landscape in the late 1990s (**Figure 11**) (Mougayar, 2016). The first layer of hardware infrastructure and protocols relates to the underlying foundational elements of Blockchain. Bitcoin, Ethereum and Hyperledger are examples of Blockchain protocols, similar to TCP/IP, HTTP and SMTP for the Internet. The second layer of middleware software and services were built on top of these protocols to extend the infrastructure, making it easier to build applications and connect them to the underlying Blockchain protocol. These include tools to create smart contracts (e.g. Solidity), general and special purpose Application Programming Interface (e.g. Neuroware) and Blockchain platforms (e.g. Esprezzo). The final layer of end-user applications is built on top of the Blockchain infrastructure and middleware. Some examples of value exchange projects include decentralised cloud storage (e.g. Storj), decentralised voting platform (e.g. Boulé) and supply chain provenance (e.g. Everledger).

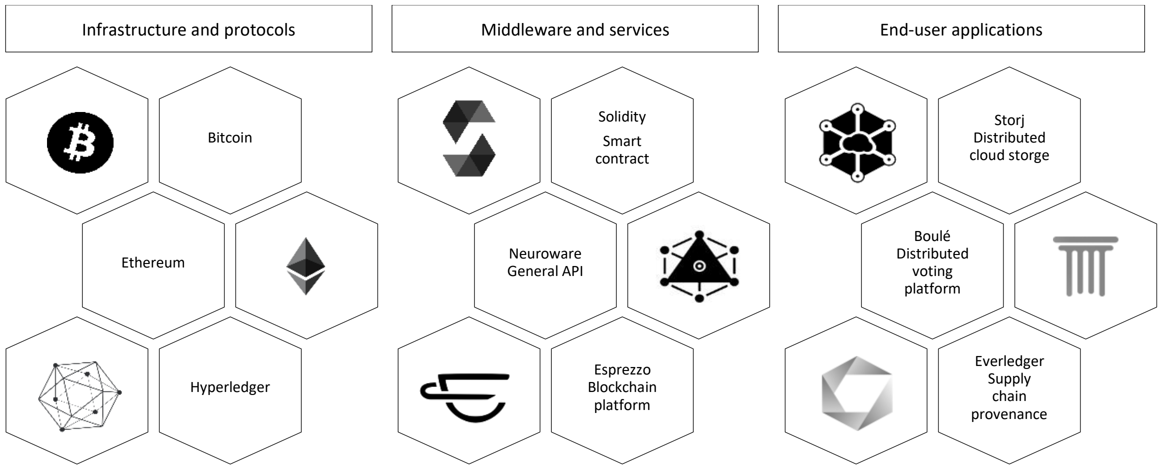

Figure 11 – Blockchain overview (Mougayar, 2016)

Blockchain as an inter-organisational track and trace capability

Blockchain is capable to process transactions and has the potential to hash any tangible and intangible asset. Based on this functionality, a huge body of literature emerged with focus on four Blockchain use-case areas (Walport, 2016; Mougayar, 2016; Morabito, 2017; Pilkington, 2015; Gupta, 2017; Matilla, 2016; Crosby, Nachiappan, Pattanayak, Verma, & Kalyanaraman, 2016): 1) financial services (e.g. commercial trading, trade finance and cross-border transactions); 2) government services (e.g. digital identification of citizens, digital voting processes); 3) supply chain management (e.g. asset tracking, provenance assurance); 4) Internet of Things (e.g. record IoT interactions).

This research focuses on the use-case area of supply chain management, where it is deemed possible to use the Blockchain to register and maintain details on the provenance of any asset throughout its lifecycle (Morabito, 2017). Permissioned participants are able to create, manage, transfer and access the details without delays or centralised intermediaries, thus establishing transparency throughout the supply chain. With the Blockchain, parts of the supply chain reach consensus on a shared ledger that is signed digitally, ensuring that the documents and certifications have not been manipulated in any way. A practical example is Everledger, which is a distributed diamond certification database that uses laser-inscribed serial numbers to track the movement, the ownership, and other events of diamonds (Matilla, 2016). Using Blockchain for supply chain to track assets can solve three important problems (Walport, 2016; Morabito, 2017):

- The problem of relying on potentially manipulated paper documents to prove asset origin, which the Blockchain solves by recording and validating all activity of an asset throughout its lifecycle;
- The problem of counterfeit assets ending up in the supply chain, which the Blockchain solves by improving information sharing practices as an anti-counterfeit solution;
- The problem of lack of IT standards to maintain local copies of asset data, which the Blockchain solves by presenting data that is continuously synced and easily accessible through an overlay that is used by all supply chain participants.

It is possible to position this research within existing scientific literature that is focused on identifying the impact of Blockchain on supply chain transparency. A prominent example is the usage of Blockchain and RFID to refine the existing centralised food supply chain traceability system (Tian, 2016). Tian compares two conceptual frameworks that makes it visually clear how the overall supply chain dynamics change with Blockchain adoption. It shows that in the current situation supply chain participants must contact the information supervision centre in order to acquire data on food safety. In the new Blockchain-based environment, all supply chain participants are able to acquire this data from the Blockchain overlay. This transition changes the overall position and dynamics between the supply chain participants and the IT systems that they interact with, because information asymmetry is reduced. Despite the advantages to improve traceability and credibility of the information shared throughout the supply chain, the immaturity of Blockchain technology and the high cost of RFID impose barriers for adopting the solution.

Other researchers also identified the disruptive potential of Blockchain to achieve transparency in supply chain networks (Korpela, Hallikas, & Dahlberg, 2017; Pflaum, Bodendorf, Prockl, & Chen, 2017; Hua & Notland, 2016). It is considered important to effectively share information in order to meet customer demand. The necessity to improve supply chain visibility is motivated due to the presence of intermediaries that are specialised in establishing interoperability between supply chain participants, which can result in high transaction costs. Based on a survey with business managers from 30 companies, Korpela et al concludes that the distributed ledger technology and smart contracts are seen as the most valuable properties to process transactions (Korpela, Hallikas, & Dahlberg, 2017).

Through a multiple case study, another research was focused on identifying the ability of Blockchain to meet key supply chain management key performance indicators, such as cost, speed, dependability, risk, reduction, sustainability and flexibility (**Table 4**). With Blockchain, all transactions can become auditable, which is important in developing trust among interested parties. However, the challenge is to allocate resources to incentivise supply chain members to participate in the Blockchain ecosystem (Kshetri, 2018).

Table 4 – Contribution of Blockchain to strategic supply chain objectives (Kshetri, 2018)

Supply chain KPI	Blockchain value proposition
Cost	Financially sound to engage with Blockchain, especially when IoT is already used to track key supply chain processes.
Speed	Increased by digitising physical process and reducing physical interactions and communication.
Dependability	Blockchain-based digital certification is used as a means to increase dependability and to ensure that supply chain partners take responsibility and accountability for their actions.
Risk reduction	Only parties that are mutually accepted in the network can engage in transactions, which reduces cybersecurity risk.
Sustainability	Possible to validate the identities of supply chain participants and IoT enabled processes.
Flexibility	The network effect take place when only a few participants use the Blockchain.

Asset provenance is identified as an important research and business problem, since it is often not possible or difficult to track the assets that are part of a complex, international and inter-organisational supply chain network (Kim & Laskowski, 2016). However, with changes in the governance of business networks and distribution of supply chain tasks, it raises the question to what extent this impacts existing business models (ECRIM, 2017).

Blockchain risks and limitations

Another matter pertaining Blockchain adoption relate to the risks and limitations of the technology, which relate to the following concepts (Smith, 2013; Swan, 2015):

- Limited scalability: The core benefits of Blockchain come at the expense of the throughput and latency of transactions that the network can process. It is limited to process a huge number of transactions.
- Limited privacy: Given the Public-Key infrastructure for public Blockchains, transactions that may appear private may be linked to the identity of an entity based on transactions patterns.
- Immutability: It is possible for invalid data (e.g. through error in RFID) or faulty data (e.g. as a result of human error) to end up on Blockchain, which due to its immutability cannot be corrected. This is also known as the Garbage-In Garbage-Out principle.
- Storage constraints: With an indefinite amount of data stored by every node in the network, parties could face disproportional costs for any viable use case.
- Unsustainable consensus mechanism: Current consensus mechanisms, such as Proof of Work, requires huge amount of computation power that results in massive waste of energy.
- Government regulation: One of the most significant factors and risks of Blockchain relates to the extent to which government regulation would support or hinder Blockchain adoption.
- Business Model alignment: A concern faced by enterprises is whether Blockchain can allow them to leverage their existing business models.
- Quantum computing threat: Though limited, quantum computers theoretically are capable to break Public-Key algorithms. The current Blockchain infrastructure is currently insufficiently prepared for the emergence of quantum computing.

2.2.2 Blockchain ecosystem

The second part delves into the design and dynamics of a Blockchain consortium with focus on: 1) ledger typologies; 2) Blockchain network typologies; 3) Blockchain consensus mechanisms; 4) Blockchain consortium.

Ledger network typologies

It is possible to identify three types of ledger networks and illustrate why switching between these networks influence the interaction dynamics of the business ecosystem (Baran, 1964) (**Figure 12**). Business network participants currently rely on IT systems to manage the lifecycle of their assets and financial transactions (Walport, 2016). The participants of these ecosystems are required to engage in a process of reconciliation to assure that their data is connected and synchronised with different systems of different entities. Traditionally, business network participants are connected through a single, centralised system to access data. However, even though this model assures administrative control, it is criticised to reduce the transparency of the ecosystem as it can easily exclude network participants (Morabito, 2017). Alternatively, with decentralised systems the data is spread across a collection of nodes and individual work stations (Morabito, 2017). Distributed ledgers are spread across organisational and geographic boundaries, spanning countries and institutions (Swan, 2015). The difference between decentralised and distributed ledgers relates primarily to data storage and the ability of the Blockchain to capture business transaction logic. With decentralised ledgers, individual workstations that require specific data must find the respective node on which this data is stored. With distributed ledgers, historical and current data is stored on all nodes of the network that are continuously connected and synchronised. A value transaction between two participants is immediately recognised by the entire network, which reduces reconciliation and administration (Swan, 2015; Walport, 2016; Garzik & Donnelly, 2018; Morabito, 2017).

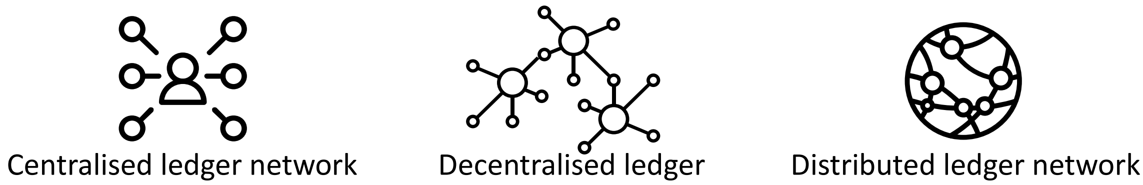

Figure 12 – Types of ledger networks (Walport, 2016)

Blockchain network typologies

Based on the key ability of Blockchain to set user permissions, existing literature identified four Blockchain typologies (**Figure 13**) that determine whether the Blockchain is public or private and permissionless or permissioned (Pilkington, 2015; Morabito, 2017; Walport, 2016):

- Public permissionless Blockchain: A network in which there are no restrictions on who can read, write and validate data on the Blockchain. These participants are not necessarily known or trusted. Examples include Bitcoin and Ethereum.
- Public permissioned Blockchain: A network in which there are no restrictions on who can read or write data on the Blockchain. However, there are restrictions on who can participate in the consensus process. Ripple is an example, where the public can engage in transactions and only authenticated banks engage in consensus processes.
- Private permissionless Blockchain: A network in which there are restrictions on who can read and write data on the Blockchain. However, there are no restrictions on who can participate in the consensus process. This hybrid model is not used at all.
- Private permissioned Blockchain: A network in which there are restrictions on who can read, write and validate data on the Blockchain. These participants are typically known and trusted through organisational Know-Your-Business and Know-Your-Customer processes that white or blacklist users. When these networks involve more than one organisation, the network is known as a *Blockchain consortium*.

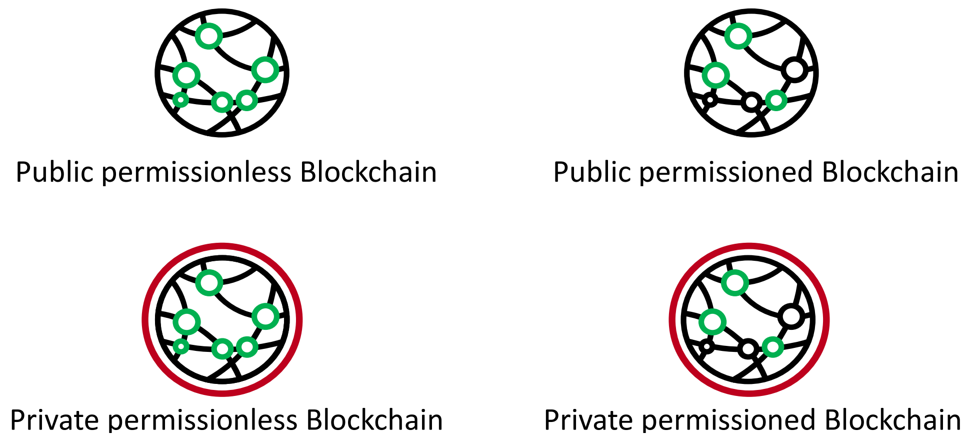

Figure 13 – Types of Blockchain networks (Walport, 2016; Morabito, 2017; Pilkington, 2015)

Based on these typologies, Dave Birch from Consult Hyperion formulated a taxonomy that highlights which Blockchain network would be suitable for which scenario (Figure 14).

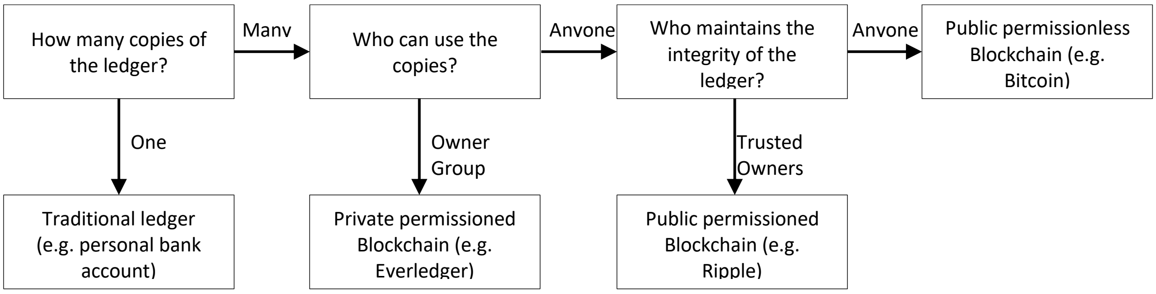

Figure 14 – Blockchain taxonomy (Walport, 2016, p. 19)

Blockchain consensus mechanisms

Throughout the ecosystem, the participating users send or receive transactions and engage in validation procedures to reach agreement on the state of the ledger and which transactions should be added (Swanson, 2015). Scientific literature typically focuses on three consensus mechanisms that support this procedure (Morabito, 2017; Pilkington, 2015; Matilla, 2016; Baliga, 2017):

- Proof-of-Work: As seen with Bitcoin and other permissionless Blockchain networks, the chain with the most historical validation is accepted as the valid ledger by solving mathematical hashing computation with CPU power. It provides strong immutability of record at the cost of high energy consumption.
- Proof-of-Stake: With Proof-of-Stake, validators must attain ownership of a certain percentage of scarce tokens to become the dominant node in the permissioned or permissionless Blockchain network and determine the valid ledger. As an alternative to Proof-of-Work, Proof-of-Stake engages in mathematical hashing computation only in limited search space. As a result, transactions are processed faster and the system is more energy efficient. The risk is that centralisation might occur when nodes become too dominant in the network.
- Practical Byzantine Fault Tolerance: This consensus mechanism is used with permissioned Blockchain networks, such as Hyperledger Fabric. This mechanism assumes that the group of participants is known, registered and verified within the Blockchain consortium. The underlying algorithm is designed to validate the ledger once a considerable amount of node responses is signed, eliminating the energy costs associated with hashing protocols. This consensus mechanism is typically supported by business networks.

Blockchain consortium

The holistic perspective on the Blockchain ecosystem shows that users can receive permission to read, send and receive transactions and validate in consensus processes. Unfortunately, the problem is that existing scientific literature does not explicitly identify which parties typically operate in a private permissioned Blockchain consortium. To reduce this gap, IBM identified typical participants and components of these consortiums (Gupta, 2017) (**Figure 15**):

- Blockchain user: Any business entity or institution that is permissioned to join the network and conduct Business-to-Business transactions with other participants.
- Regulator: An entity with special permissions, such as the EASA, that only oversees transactions happening within the network.
- Blockchain operator: An entity with the authority to allocate and manage permissions within the Blockchain network.
- Blockchain developer: Programmers that write the underlying Blockchain code, the client applications, and smart contracts that enable the users to conduct transactions.
- Blockchain architect: An entity who designs the overall Blockchain infrastructure and ecosystem.
- Certificate Authority: An entity who issues and manages the types of certificates that are required to run a permissioned Blockchain.
- Traditional processing platforms: Existing computer systems that may be used by the Blockchain to process and verify transaction attempts made by a business user.
- Traditional data sources: Existing databases that provide data to influence smart contracts and define how data is transferred to the Blockchain.

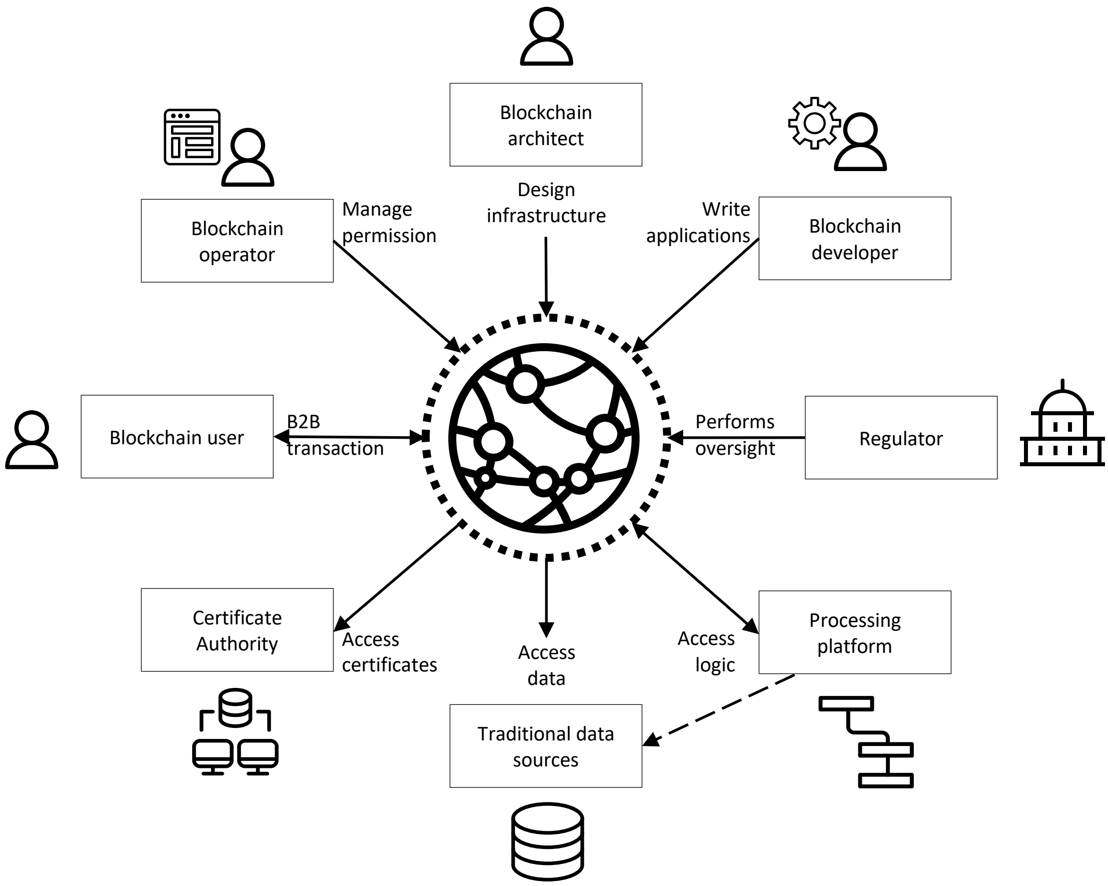

Figure 15 – Permissioned blockchain ecosystem (Gupta, 2017)

2.3 Design synthesis

Based on literature on aircraft spare part management and Blockchain technology, this paragraph combines the knowledge in order to evaluate: 1) the need to improve aircraft spare part track and trace performance (**2.3.1**); 2) why Blockchain should be used to track and trace aircraft spare parts (**2.3.2**); 3) the impact of Blockchain on aircraft spare part data presentation (**2.3.3**); 4) the impact of Blockchain on aircraft spare part ecosystem (**2.3.4**); 5) the impact of Blockchain on the information and asset flow (**2.3.5**); 6) the ability of Blockchain to meet industry and system requirements (**2.3.6**).

2.3.1 Evaluating the need to improve aircraft spare part track and trace performance

To ensure that an aircraft and its components are legally certified and considered airworthy, it is necessary to analytically predict when it is necessary to enter the maintenance process to restore aircraft safety and reliability. It is important to assure that aircraft spare parts are operationally available when the decision was made to engage in aircraft maintenance, which shows why aircraft spare part management is an important key activity. The success of aircraft spare part management relates to the ability to adequately track and trace these components internally throughout the organisation and externally throughout the supply chain. Every change in the part movement, ownership and condition due to modification, maintenance, lease and exchange must be reported and communicated to assure airworthiness. Therefore, it is not a surprise why the IATA emphasises the importance to track and trace the components throughout its lifecycle and the quality of the component traceability data. This data records and exchanges insight on the part location, ownership, maintenance and usage history between aviation supply chain participants even after the aircraft is manufactured and delivered. However, it is difficult to manage the traceability data for four reasons: 1) nature of aircraft configuration: an aircraft can have millions of components with unique part numbers; 2) nature of spare part management: components can be installed, removed, repaired, maintained, stored, shipped and have multiple owners; 3) nature of aviation supply chain: it is complex, distributed, multi-stage and global; 4) nature of communication: traceability data is shared through outdated Business-to-Business channels. Assuring optimal track and trace performance can assure supply chain agility by reducing information asymmetry and improve maintenance decision-making processes. This performance is related to the quality of the traceability data, which is characterised by the extent to which the data is complete, timeliness and accurate. Thus, improving the performance can hypothetically lead to operational (e.g. inventory accuracy), legislative (e.g. regulatory compliance) and safety (e.g. reduced counterfeit products) benefits. Unfortunately, existing RFID solutions do not entirely satisfy industry requirements, since there are still concerns about how information is stored, communicated, synchronised and accessed.

2.3.2 Evaluating why Blockchain should be used to track and trace aircraft spare parts

Blockchain has been intensively researched in the application of supply chain management with the purpose to address the problem of asset provenance, document manipulation, presence of counterfeit assets and lack of IT standards to maintain asset copies. The capability of Blockchain to hash both tangible (e.g. aircraft spare parts) and intangible (e.g. Certificate of Airworthiness) assets highlights its potential as an inter-organisational aircraft spare part track and trace capability. The hashed aircraft spare parts would be recognised as smart properties and receive a unique identification code that makes it possible to track, control and exchange its ownership. These transactions will be recognised as a block by the Blockchain network and added to the previous chain of blocks once the network reaches consensus to validate the spare part transaction. When it is validated, any participating member (e.g. MRO, OEM, regulator) would immediately audit the block and understand the changes in the part movement, ownership and condition. From a track and trace perspective, each transaction is recorded onto the distributed ledger, allowing to see what happens with the part in real-time.

Blockchain improves information sharing practices by removing the necessity to acquire traceability data through centralised databases, since the data is stored on each node. As a result, supply chain transparency increases since each node of each participant is synchronised with the overall Blockchain network. This is an improvement over the situation where multiple ledgers are held at multiple parties, which could potentially include traceability data that is not synchronised. As an example, the Blockchain could manage part traceability by providing records on Service Bulletins or Certificate of Airworthiness at each significant event. Assuming each part is RFID and IoT enabled, it would potentially be possible to use this data as input for smart contracts that could then automatically generate these certificates. However, the most important contribution is that the Blockchain could be used as an architecture that is accessible by different participants that require data on the related aircraft spare part. Adhering to IATA's vision, the potential of the Blockchain to act as an inter-organisational track and trace capability could impact aircraft spare part logistics, maintenance workflows, customer report and asset management activities.

2.3.3 Evaluating the impact of Blockchain on aircraft spare part data presentation

If any information is shared on the Blockchain for the purpose to track and trace aircraft spare parts, it is important to assure that the traceability data is Spec 2000 compliant. This means that the Blockchain must at the very least acquire and present information from the Spec 2000 database on the component CAGE code, part serial number, current part number, action company, action date and action codes. Additionally, the Blockchain could acquire information on the component limitations, status change, log books, Service bulletins, product attributes. Based on previous Blockchain Proof of Concepts developed by Accenture, an artistic visualisation was made to highlight how end-users could interact with the Blockchain through an online application called the Digital Warehouse (**Figure 16**).

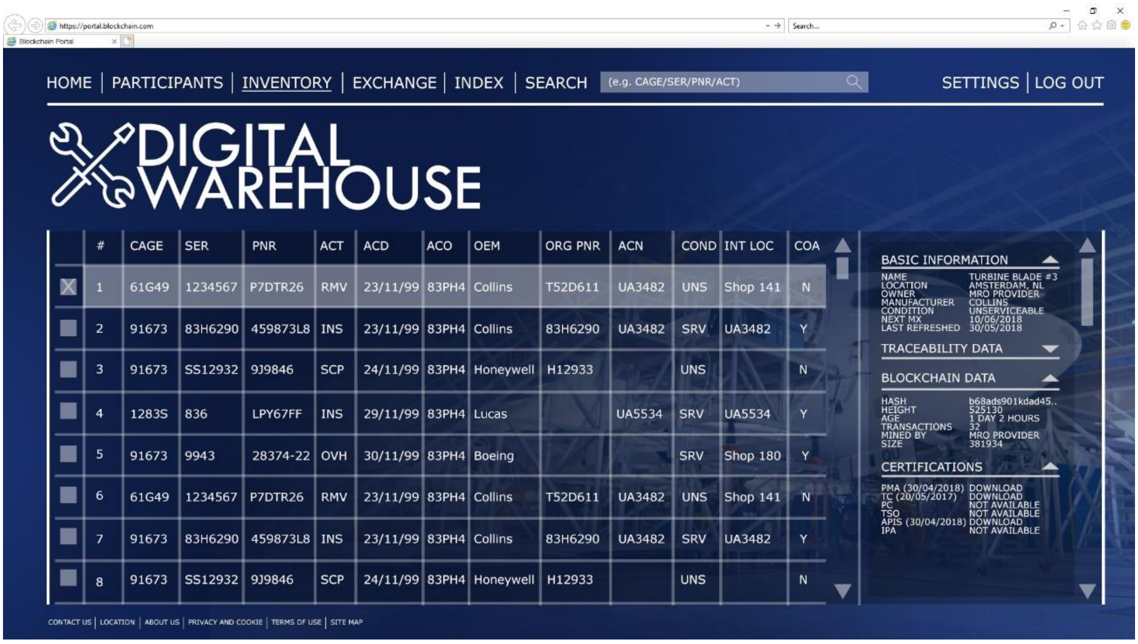

Figure 16 – Artistic visualisation of a potential Blockchain user interface

2.3.4 Evaluating the impact of Blockchain on the aircraft spare part ecosystem

A more important consideration is how widespread Blockchain adoption could impact the aircraft spare part ecosystem. Currently, this ecosystem is characterised by a network of key actors that interact with the Spec 2000 database in order to acquire or exchange traceability data. Based on academic research and Accenture insight, it is clear that in the Blockchain-based ecosystem all participants would access the date through Blockchain that is connected with legacy databases and systems. This supports further semantics standardisation by ensuring that all parties adopt Spec 2000 compliant traceability data, if this is not the case yet.

This raises the question how the new Blockchain ecosystem should be designed to accommodate the traditional aircraft spare part ecosystem. This is characterised by the ledger network, Blockchain network, consensus mechanism and the role of each participant. The adoption of Blockchain immediately implies a transition to a distributed ledger network, where participants sacrifice administrative control and data ownership to gain supply chain transparency. Based on the Blockchain taxonomy, it is also immediately clear that it is necessary to adopt or construct a private permissioned Blockchain network in which only permissioned participants can read, edit and validate data. This is typically adopted by business networks where sensitive data is exchanged within or across network participants that are known and validated by Know-Your-Business processes. In these permissioned Blockchains, it is typical to adopt the Practical Byzantine Fault Tolerance consensus algorithm, since it allows high-throughput transactions without the necessity of opening the ecosystem to large public groups.

The Blockchain consortium (**Figure 17**) would include key parties, such as aircraft operators, MRO providers and OEMs. These participants engage in Business-to-Business transactions (e.g. an aircraft operator that sends an unserviceable component for repair at an MRO provider). Additionally, it would be possible to include secondary stakeholders, such as IATA, EASA and the FAA, that oversee all transactions and changes in component location, ownership and status. This oversight would ensure that supply chain participants maintain accountability over their track and trace practices. Ultimately, the Blockchain would be connected to the Spec 2000 to acquire data and to other traditional processing systems in order to acquire business logic.

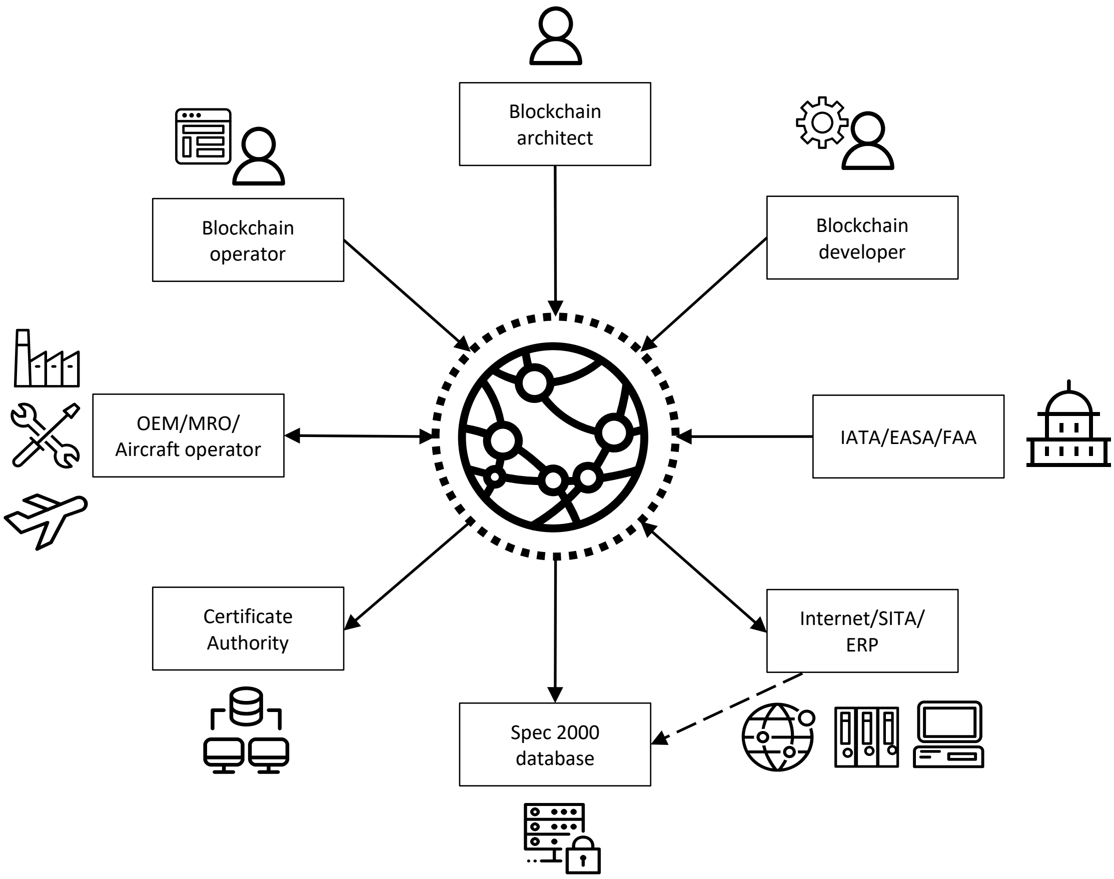

Figure 17 – A Blockchain-based aircraft pare part ecosystem

The remaining concern is determining which party would be considered the Blockchain operator, architect and developer. Each party might want to stake ownership over the Blockchain network, especially parties who currently maintain ownership over maintenance and traceability data.

Given the regulatory nature of the aviation industry, it is possible to hypothesise that it might be beneficial to allocate the operating authority to the regulator. However, this conflicts with the actual role and function of Blockchain regulators, who must only perform oversight and not engage with authorisation. Thus, it might be ideal for regulators to work together with an independent third-party consortium, such as IATA, to authorise MROs, OEMs and operators to enter the Blockchain network. Given the novelty of Blockchain technology, it is understandable that the aviation industry might face bottlenecks in designing and developing a Blockchain architecture. This requires identifying the parties with whom aviation industry members would develop the solutions and how the underlying technological architecture would be designed. Given the nature of this strategic research, establishing the technological trade-off and architecture is beyond the scope of this research.

2.3.5 Evaluating the impact of the Blockchain on the information and asset flow

For this discussion, focus is directed towards one of the previously included example of an interaction between an aircraft operator and MRO provider, where unserviceable components are exchanged for serviceable components. Rather than capturing this process in a business process map, this process is here presented in a simplified overview (**Figure 18**).

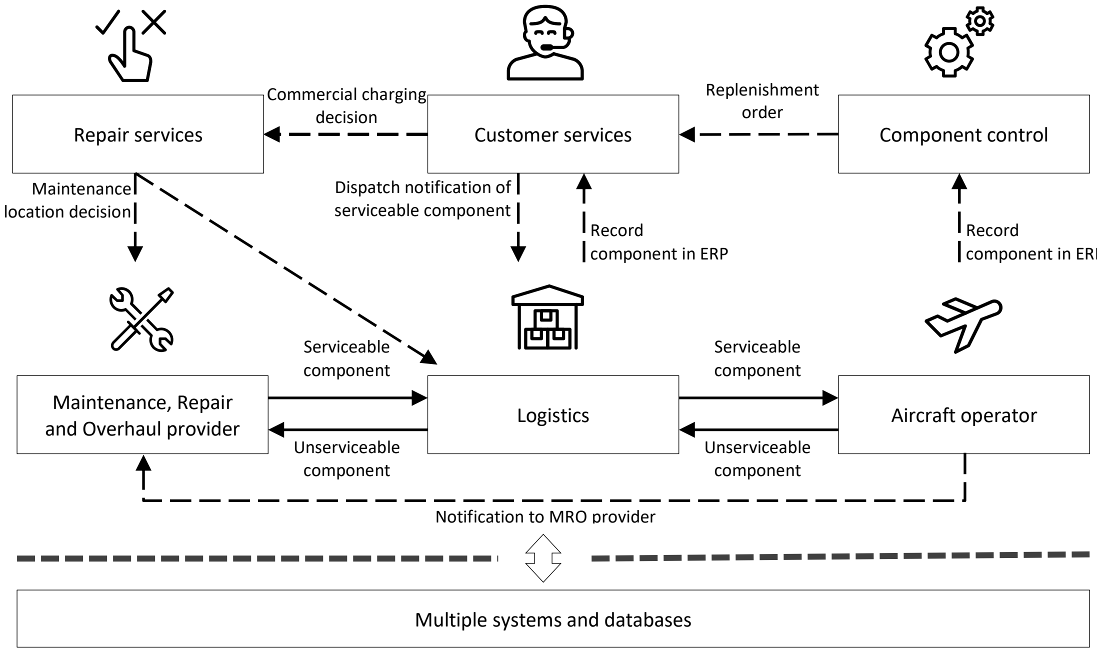

Figure 18 – The current state aircraft spare part asset and information flow

The usage of Blockchain would not impact the asset flow, given how inventory is managed throughout the aircraft spare part supply chain according to IATA practices. However, the impact can be identified in the information flow, how the underlying parties communicate with each other, and how parties engage in decision-making processes (**Figure 19**). In the new environment where each asset is encoded on the Blockchain, communication flows occur less frequently. This is because the Blockchain would record all relevant changes in the aircraft component location, ownership and status. These changes can be recorded by scanning RFID and IoT-equipped aircraft spare parts rather than manually updating the ERP systems. As a result, throughout the entire process all involved participants are able to witness any update in the spare part. The process implications include and are not limited to: logistics can dispatch serviceable and unserviceable components more efficiently; repair services, customer services and component control can make decisions and orders more quickly; all ecosystem participants (e.g. aircraft operators, OEM, MRO, logistics, regulators, component control) can oversee the process more accurately in real-time since every component change is recorded and communicated through Blockchain.

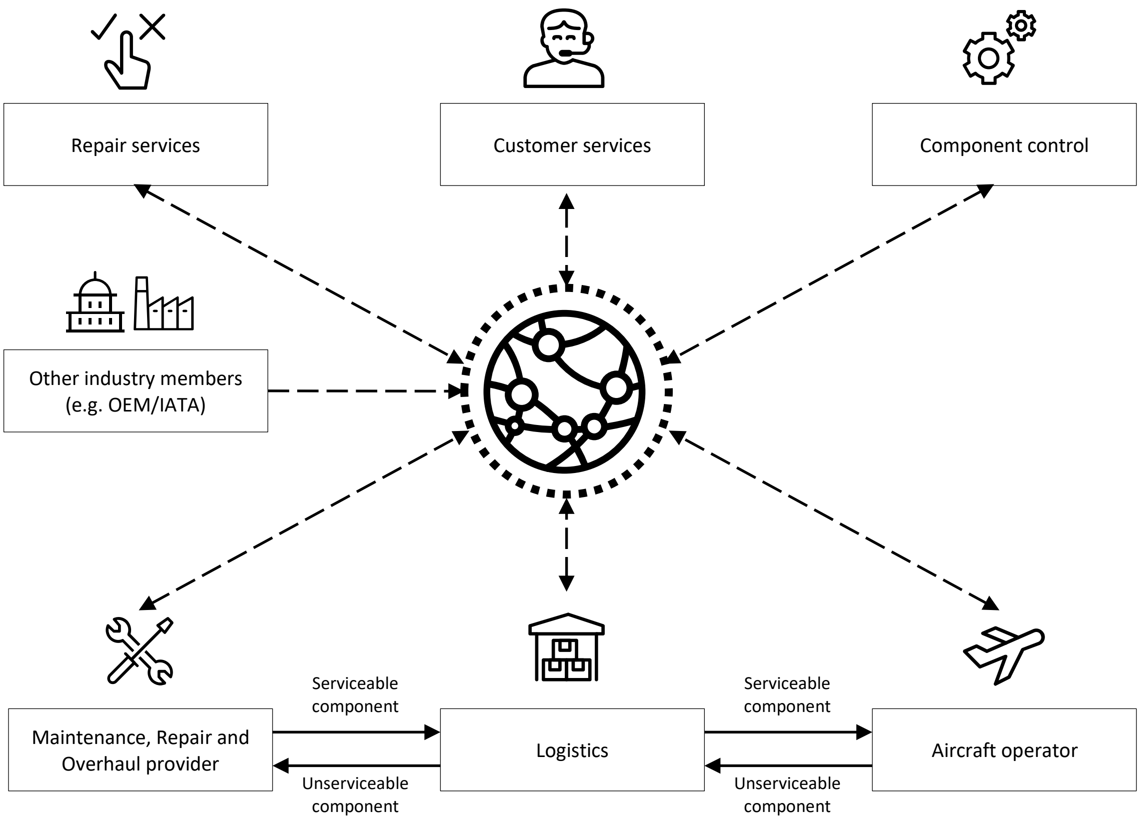

Figure 19 – The future state aircraft spare part asset and information flow

2.3.6 Evaluating the ability of Blockchain to meet industry and system requirements

It is important to understand the notion that Blockchain is merely a distributed database and not a technology like RFID that actually tracks and traces assets. The value of Blockchain as a track and trace capability is to improve control on how the traceability data is stored, communicated, synchronised and accessed. What this means is that Blockchain alone cannot fulfil the industry and system requirements and must be complemented by other track and trace technologies (e.g. barcodes, RFID, IoT). When these technologies are not utilised, the strategic value of Blockchain is diminished as it does not have the capability to provide accurate, real-time and complete traceability data. Furthermore, it is important to align these track and trace technologies with existing IT infrastructures (e.g. ERP). If this alignment is considered problematic, it is difficult to envision an environment in which Blockchain is used to track and trace aircraft spare parts.

Different aircraft spare parts are tracked for specific purposes under certain assumptions. It is more likely to use Blockchain to track and trace rotable spare parts (e.g. wheel/landing gears), since these components are considered more complex, critical and valuable. Additionally, it is possible that there are spare parts that cannot be tracked and traced, either since the components are not tagged or because there is no regulatory need to track them. To deal with this uncertainty, it is possible to develop a Blockchain Proof of Concept that assumes the starting point of including a RFID tagged engine limited life part (e.g. high-pressure turbine rotor disk) or aircraft rotable spare parts (e.g. brakes) that can also provide information on component condition (e.g. lifecycle, brake pressure).

Once the technical, functional and network related challenges have been addressed, it is possible to adopt Blockchain as an inter-organisational communication tool among supply chain participants. This would act as an alternative to traditional communication tools and protocols, such as instant messaging, phone and mail-based communication. Driven by legislation and the need to improve efficiency, disperse intra- and inter-organisational supply chain participants could use the Blockchain in order to access and audit the same real-time, accurate and complete traceability data set. While the Blockchain does not necessarily change how the actual components are technically tracked or traced, it does change how this information is communicated and exchanged. Instead of manually updating ERP systems, RFID tags are scanned throughout the component lifecycle and updated on the Blockchain. This allows regulatory institutions to immediately see what happens with each component throughout its lifecycle, which reduces the costs of compliancy and reconciliation where different entities must ensure that the data is synchronised between disperse IT systems. Additionally, data from IoT sensors on equipment (e.g. temperature, humidity, pressure) can help quantitatively describe the quality and condition of an asset. The traceability and reliability data can be incorporated into smart contracts in order to automatically generate aircraft certification documents, reducing administrative paperwork. This discussion shows why Blockchain is able to meet all industry requirements and why it is currently not possible to identify whether Blockchain meets all system requirements (**Table 5**).

Table 5 – Ability of Blockchain to meet industry and system track and trace requirements

Industry requirements	System requirements
Item identification: Blockchain is capable to hash any item and provide it with a unique digital fingerprint, typically captured by its hash value.	*Business drivers:* This research focuses on identifying the ability of Blockchain to meet operational and legislative drivers by evaluating the MRO business model.
Document and asset tracking: Blockchain provides the opportunity to track and trace spare parts, tools and its documentation in real-time with accuracy.	*Application characteristics:* Subsequent research must focus on developing technical frameworks and applications to allow end-user interaction through a Blockchain Proof of Concept.
Automatic information capture: The system could automatically be updated with blocks of transactions once RFID tags are scanned and uploaded into the system.	*Information management:* Subsequent research must focus on aligning and integrating the Blockchain Proof of Concept (including RFID and IoT) with MRO IT systems (e.g. ERP).
Complete part information: If the aircraft spare part is provided with RFID tags during manufacturing, it is possible to acquire the full history of the components.	*Data processing:* Subsequent research must experiment with data synchronisation between supply chain participants (e.g. MRO/Aircraft Operator) through Blockchain.
Automatic certificate generation: Smart contracts can facilitate automatic certificate generation by feeding certain traceability and reliability data into airworthiness certification documents.	*Functional requirements:* Subsequent research must focus on ensuring that the Blockchain Proof of Concept does not interfere with aircraft equipment and meet airworthiness criteria.
	Numbering standards: Subsequent research must focus on ensuring that the Blockchain Proof of Concept is capable to comply with Spec 2000 traceability directives.

2.4 CONCLUSION

This chapter assumed multiple roles: 1) to provide the reader with a theoretical background on the complex concepts and relationships of aircraft spare part management and Blockchain technology; 2) to consider previous work, pitfalls and gaps in academic research; 3) to critically evaluate whether it is possible to use Blockchain for aircraft spare part management. Based on the desk research, it is possible to address the first research question:

How is Blockchain capable to track and trace the movement, modification and maintenance of aircraft spare parts and communicate it throughout the whole aviation supply chain?

Through theoretically grounded research, a Blockchain use case was hypothesised on the premise that it can improve aviation supply chain and ecosystem transparency. With the capability to hash both tangible (e.g. aircraft spare parts) and intangible (e.g. Certificate of Airworthiness) assets, Blockchain can be extended to the MRO industry as an aircraft spare part track and trace capability. This concept is already used to track and trace cars (e.g. Bitcar), coffee beans (e.g. Tony Chocolonely) and diamonds (e.g. Everledger). The hashed aircraft spare parts would be recognised as smart properties and receive a unique identification code that makes it possible to track, control and exchange its ownership. These transactions will be recognised as a block by the Blockchain network and added to the previous chain of blocks once the network reaches consensus to validate the transaction. When it is validated, any participating member (e.g. MRO, OEM, operator, regulator) would immediately be able to audit the block to verify changes in the aircraft spare part movement, ownership and condition.

If any information is shared for the purpose of tracking and tracing aircraft spare parts, it is important to assure that the Blockchain traceability data is Spec 2000 compliant. This means that the Blockchain must at the very least acquire and present information on component CAGE code, part serial number, current part number, action company, action date and action codes. Additionally, the Blockchain could acquire information on component limitations, status change, logbooks, Service Bulletins and product attributes. With this, the Blockchain can function as an inter-organisational digital distributed component logbook among known and trusted supply chain participants in a controlled network where component RFID-based traceability data and IoT-based reliability data can be exchanged.

It is likely that the Blockchain will be used to only track and trace rotable aircraft spare parts (e.g. wheel/landing gear). These components are more complex and critical to flight operations, which classifies them as financially valuable assets. Additionally, these components have an indefinite lifecycle compared to their repairable and expendable counterparts, which means that they can often enter maintenance, repair and overhaul. It is unlikely that the aviation industry will track individual expendable parts (e.g. lamps) but might consider tracking and tracing a box full of repairables or expendables.

However, the Blockchain is subject to various risks and limitations that raises the question whether it is desirable to adopt the technology. Limited scalability and storage constraints become major issues when components are extensively exchanged between aviation industry participants, which could result in disproportionate costs for the industry participants. Additionally, major concerns exist about: 1) privacy and whether Blockchain could expose proprietary maintenance data; 2) government regulation that could result in Blockchain opposition; 3) capability to leverage business models, which could determine whether enterprises would consider Blockchain.

The research focuses primarily on the third limitation by evaluating the impact of Blockchain on the MRO business model. Clarifying these incentives and trade-offs is necessary to address the systematic requirement of business drivers, which could lead to industry support for Blockchain. The next chapter is dedicated to formulate a method to support this objective.

3 EVALUATION METHODOLOGY

The third chapter is dedicated to establish a business model evaluation methodology. The chapter first engages in a desk research on business models to introduce Business Model Stress Test (**3.1**). This methodology is used to formulate and empirically validate a literature-based MRO Business Model Canvas (**3.2**) and stress factors against which the MRO business model will be confronted (**3.3**). The deliverable of this chapter is an evaluation methodology that presents the MRO Business Model Canvas and how it can be evaluated. This is discussed when the chapter reflects upon the second research question (**3.4**):

How is it possible to systematically evaluate the robustness of MRO business models when it is confronted against Blockchain as an aircraft spare part track and trace capability?

3.1 BUSINESS MODEL STRESS TEST

This paragraph provides theoretical background on the concept of business models (**3.1.1**), introduces Business Model Stress Test methodology (**3.1.2**) and defines the scope of the business model that this research will build upon (**3.1.3**).

3.1.1 Business model fundamentals

The first part delves into the fundamentals of business models: 1) introduction to business models (definition and purpose of business models); 2) business model design ontologies; 3) purpose of business model innovation; 4) evaluation of business models; 5) scenario planning.

The *Business Model* is a description or model that represents an enterprise's logic to create, distribute and capture value for its stakeholders (Chesbrough & Rosenbloom, 2002). These models are typically used by managers to systematically consider their potential options when they face any uncertainty (McGrath, 2010).

There are different ontologies and design methods that describe the business model. Despite the differences in the focus and assumptions of each ontology, these models share a set of functional business model components and design variables (e.g. value proposition, resources, customers). It is considered a time-intensive process to formulate and evaluate the business models with different design methods, which is why it is not unusual to adopt only one ontology. Previous literature identified different business model design approaches by various authors, such as Horowitz, Chesbrough, Rappa, Osterwalder, and Hamel. One of the popular ontologies is the Business Model Canvas (Osterwalder, 2004), which is focused on nine business components (key partnerships, key activities, key resources, value proposition, cost structure, revenue structure, customer relationships, customer channels and customer segments). Other popular models include the, STOF (Bouwman, Faber, Haaker, Kijl, & De Reuver, 2008) and VISOR (El-Sawy & Pereira, 2013).

In order to cope with uncertain future scenarios, enterprises engage in *Business Model Innovation* to develop a new source of competitive advantage in environments characterised by technological, regulatory, competitive and market uncertainties (de Reuver, Bouwman, & MacInnes, 2009; Giesen, Riddleberger, Christner, & Bell, 2010). The innovation process typically occurs through learning and experimentation (e.g. inclusion of new revenue models). The underlying business model components and logic change due to this experimentation.

The long-term success of business models is evaluated by its *robustness*, which relates to the ability of the business model to remain feasible and viable with changing business environments (Bouwman, Faber, Haaker, Kijl, & De Reuver, 2008; Schwarz & Rohrbeck, 2013). *Feasibility* relates to whether resources are available to implement and deploy the business model in practice. *Viability* can be assessed through a business case that evaluates the financial implications of a business model.

The robustness of business models is evaluated within uncertain *future scenarios*, which are assumption-driven plausible and challenging descriptions of how the future state may develop based on current relevant developments (Haaker, Bouwman, Janssen, & de Reuver, 2017). These developments can relate to certain trends (e.g. aging population) or uncertainties that could result in different degrees of business model robustness (e.g. technological disruption). Through scenario planning, enterprises gather insight on how business models would perform in different future environments and whether the underlying choices and assumptions supporting the business model is robust.

3.1.2 Business Model Stress Test

The second part delves into the fundamentals of Business Model Stress Test methodology: 1) introduction to the methodology (purpose and outcome); 2) description of the six-step methodology; 3) strengths and limitations of the methodology.

Introduction to Business Model Stress Test

The main objective of this research is to identify the applicability of Blockchain for aircraft spare part management and evaluate the robustness of MRO business models with changing information sharing practices. However, due to scarcity of literature on business model robustness, this evaluation is typically done non-systematically and is left to chance. Fortunately, it is possible to systematically evaluate the robustness of business model components by applying Business Model Stress Test (Haaker, Bouwman, Janssen, & de Reuver, 2017). *Business Model Stress Test* is the only known academic, systematic and practical approach to evaluate the robustness of business models in different future scenarios. During this approach the business model is subject to a stress test, where uncertainties serve as *stress factors*. This method is used in early stages of strategic formulation in order to evaluate which strategic options result to feasible and viable business models. This inspires the discussion on how it is possible to improve the robustness of certain business model components. The end goal is to create a *heat map* that confronts vertically positioned business model components against horizontally positioned stress factors.

Business Model Stress Test Methodology

The method is a six-step systematic analysis that identifies the robustness of business model components in different business scenarios (**Figure 20**).

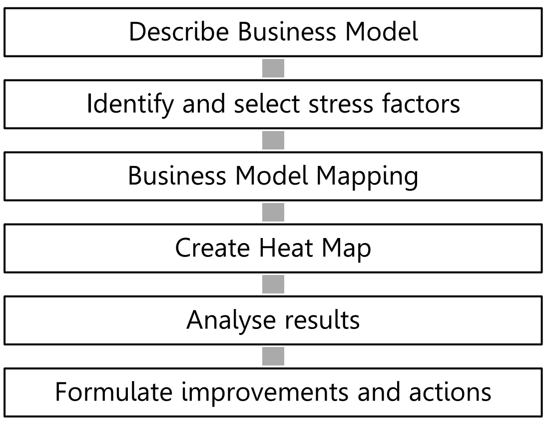

Figure 20 – Business Model Stress Test methodology (Haaker, Bouwman, Janssen, & de Reuver, 2017)

The first step of this method is to structure the business model, which acts as the unit of analysis for further research. It is possible to approach this formulation through two ways: 1) formulating the business model from previous literature; 2) translating tacit experiences to explicit business models through discussion. These business models can be structured with the aforementioned ontologies, such as Business Model Canvas, STOF and VISOR.

The second step of this method is to engage in scenario planning and identify trends, uncertainties and outcomes that will be used as stress factors. It is possible to approach this formulation through two ways: 1) formulating the factors from existing independent trend and future analysis; 2) engaging in a brainstorm session with stakeholders with trend identification methods such as PESTLE. The problem of the latter approach is that it introduces the risk of bias, since participants use previous experience to formulate familiar stress factors. Haaker et al recommends to limit to five uncertainties to prevent convoluted analysis.

The third step of this method is to explore the causal relationship between the business model components and stress factors. When these relationships are not obvious, it is necessary to delve into discussion and debate about its impact. Therefore, this step maps which stress factors impact which business model components. The combinations that highlight any impact will be included for further analysis.

The fourth step of this method is to develop the heat map, which is a matrix that vertically positions business model components against horizontally positioned stress factors. The impact of these scenarios on the business components is identified with a colouring scheme, which must also be motivated:

- Red: The business model component is no longer feasible for the stress factor.
- Orange: The business model component is no longer viable and requires revision.
- Green: The business model component is feasible and viable with positive impact.
- Grey: The business model component is not affected in any way.

The fifth step of this method is to analyse which business model components are not robust and involves two sub-steps:

- Sub-view analysis: This part of the analysis focuses on why some business model components appear more robust than others. It can explain which stress factor may have the largest positive or negative impact.
- Pattern analysis: This part of the analysis focuses on the colouring pattern of the heat map. It can explain whether specific business model components are consistently favourable or not, whether there are inconsistencies between business model components and whether these components are not feasible in any scenario.

The sixth and final step of this method is to formulate improvement and actionable conclusions. These recommendations are focused on improving weak business model components or improve business model consistency.

Business Model Stress Test strengths and limitations

The strength of this method is that it is the first structured approach to evaluate business model robustness, help identify business vulnerability and formulate informed strategic decisions. The approach is ontology-agnostic, which means that it is possible to use different modelling techniques in different contexts and domains. The academic strength of this model is that it builds upon previous literature and concepts related to business model design, innovation, evaluation and scenario planning.

The limitation of this method is that it is qualitative in nature, with no quantitative assumptions to support the research. The validity and reliability of the test depends on the quality of input: 1) expertise and knowledge possessed by participants; 2) clarity and coherence of the business model; 3) representativeness and selection of business scenarios. It shows that the weakness of the model relates to evaluating the quality of input and the subjectivity involved in determining the business scenario impact. Moreover, this model assumes a one-way directional impact from the environment to the business, unlike the reality in which enterprises typically try to enact on their environment. Additionally, the method only considers the impact of an event, not its likelihood.

3.1.3 Selection and justification of the business model ontology

The scope of the business model depends on the ontology used to further describe this model, which as previously discussed consist of a few examples. To evaluate which model will be used, a table is provided to show the criteria upon which the decision is based: the amount of business model components, the context, the strengths and the weaknesses. The decision is made to only limit to popular design ontologies that were mentioned previously, namely Business Model Canvas, STOF and VISOR (**Table 6**).

Table 6 – Overview of popular business model ontologies

Business model ontology	Number of components	Context	Strengths	Weaknesses
Business Model Canvas	9	Generic	- Well-known - Low complexity - Strategy analysis - Visual support	- Not for network services - Limited IT focus
STOF Model	4	ICT services	- ICT services - IT architecture	- More complex - Less known
VISOR Model	5	ICT services	- IT decisions - Network analysis	- Less known - Limited IT service focus

Through an evaluation between three popular business model ontologies, the decision was made to focus on Business Model Canvas for the following reasons:

- This model is most exhaustive in covering a varying range of business model components by providing additional emphasis on customers.
- This is the only model that can be applicable in any type of context (e.g. aircraft maintenance), whereas alternative models are heavily focused on ICT services.
- The simplicity of this model supports the strategic analysis that will be done by the researcher and the MRO managers/executives.
- The visual benefit this model provides ease the communication barriers between the researcher and the MRO managers/executives.
- Finally, since previous work on MRO business logic is described with Business Model Canvas ontology, it is possible to avoid interpretation bias by building upon previous academic literature (Palma-Mendoza & Neailey, 2015).

3.2 MRO BUSINESS MODEL FORMULATION

This paragraph provides a literature-based MRO Business Model, described with the Business Model Canvas. The canvas focuses on: key partnerships (**3.2.1**), key activities (**3.2.2**), key resources (**3.2.3**), value proposition (**3.2.4**), cost structure (**3.2.5**), revenue structure (**3.2.6**), customer relationships (**3.2.7**), customer channels (**3.2.8**) and customer segments (**3.2.9**).

3.2.1 Key partnerships

Key partnerships relate to the network of partners and suppliers that allow an enterprise to enable its business model. MROs engage in strategic alliances, partnerships and buyer-supplier relationships in order to secure a steady supply of aircraft spare parts. The MRO interacts with three entities in the demand driven closed-loop aircraft spare part supply chain:

- Original Equipment Manufacturers: MROs procure new aircraft spare parts from OEMs through buyer-supplier relationships. OEMs are motivated to optimise its economies of scale and reduce its operational uncertainties.
- External repair vendors: MROs send heavily damaged parts to external repair vendors in return for repaired or replaced parts. These vendors enter strategic partnerships in order to acquire knowledge or access its customers.
- Pool partners: MROs can engage in strategic alliances with other companies to establish a pool where spare parts can be exchanged or traded between the participants. This partnership reduces the risks of aircraft spare part inventory.

3.2.2 Key activities

Key activities relate to the most important activities that an enterprise must focus on in order to run its business model. MROs engage in various problem-solving activities in order to ensure that it can provide value to its customers. The MRO key activities include:

- Reception and repair of unserviceable components: MROs receives unserviceable components from its customers and engages in planned and unplanned maintenance to assure that the components are considered airworthy.
- Replenishment and dispatch of serviceable components: MROs are required to engage in inventory management to ensure it has an optimal stock of serviceable components and dispatch it to its customers.
- Condition monitoring and analysis: MROs are required to monitor and diagnose the components for financial, regulatory and operational purposes. Data on these components allow MROs to monitor and predict component status and maintenance.

3.2.3 Key resources

Key resources relate to the physical, intellectual, human and financial assets that an enterprise owns or leases in order operate its business model. The MRO key resources include:

- Physical: This relates to capital-intensive aircraft spare part and tool inventory, hangar space, IT systems (e.g. ERP/health management), vehicles, machines and distribution networks.
- Intellectual: This relates to the MRO brand, presence of proprietary knowledge and experience (e.g. specialised engine maintenance), partnership and customer data.
- Human: This relates to the presence of experienced mechanics and engineers that assure that aircraft spare parts are monitored and maintained to airworthy condition.
- Financial: This relates to cash, credit and funds that an MRO might acquire for heavy maintenance.

3.2.4 Value proposition

Value proposition relates to the products and services that allows an enterprise to create value for its customers by solving their problems or by satisfying their needs. The MRO value proposition include:

- High quality maintenance, repair and modification services for single and integrated components at optimised costs and short Mean Time to Repair.
- Optimal spare part availability by providing access to on-site consignment and company central spare part stock.
- Provide component sale, loan and exchange services.
- Provide component management and support services.
- Provide component maintenance and logistics coordination services.

3.2.5 Cost structure

Cost structure relates to the expenses an enterprise must incur in order to sustain its business model. MRO business models are typically cost driven, which is not a surprise since aviation enterprises are typically focused on automation and achieving lean operations. The MRO cost structure includes:

- Fixed costs: These costs do not change over the volume of maintenance service provision. These include engineering personnel, transaction costs and IT system. However, a majority of MRO costs actually vary with the amount of maintenance work.
- Variable costs: These costs change proportionally with the volume of maintenance service provision, especially when it concerns unplanned maintenance. These costs are related to maintenance personnel, transportation, capital (e.g. part and tool, vehicles, machines), hangar facilities, and OEM part purchases.

3.2.6 Revenue structure

Revenue structure relates to profit and volume streams that an enterprise generates after successfully offering its value proposition to customers. The MRO revenue structure includes:

- Single component: These are transaction revenues from one-time payments. They are typically low volume in nature, since maintenance on these components occur on request rate (e.g. due to sudden failure). However, due to the need for maintenance, the profit margin is typically higher as dynamic pricing mechanisms (e.g. negotiation) increase the service fee.
- Integrated components: These are recurring revenues from ongoing payments. They are typically high volume in nature, since maintenance on these components occur on contract rate. Even though dynamic pricing mechanisms (e.g. negotiation, market supply and demand) influence the contract, fixed pricing mechanisms (e.g. type of service, type of component, frequency of service) also affect the profit margin. Even though the profit margin might be lower than for single component services, the overall revenues are higher due to the higher frequent nature of the maintenance.

3.2.7 Customer relationships

Customer relationships relate to the type of personal and automated relationship an enterprise establishes with specific customer segments, typically for customer acquisition and retention. Due to the complexity of the products and services offered by MROs, it is unusual for them to approach their customers with automated or self-services. The relationship is typically maintained by dedicated customer representatives who provide continuous support to operators per aircraft type. These key account managers ensure that deep and intimate relationships are established over a long period of time.

3.2.8 Customer channels

Customer channels relate to the communication, distribution and sales channels that connects an enterprise with its customers. Enterprises uses these channels to raise awareness, help customers evaluate, allow product and service purchase, deliver value propositions and provide after sales support. The MRO customer channels include owned direct channels (e.g. sales force, website, phone and mail) and partner indirect channels (e.g. partner-owned websites).

3.2.9 Customer segments

Customer segments relate to the different groups of organisations or individuals that enterprises must reach and serve. These customers can be segmented if their needs are justified by distinct value offers, are reached through different channels, require different relationships, have different profit implications and are willing to pay for different aspect of the value proposition. It is also possible to serve a large mass markets of customers who all have similar needs and problems. However, MROs typically focus on the niche market of aircraft operators, from whom MROs receive unserviceable components. However, it is not unusual for MROs to engage in maintenance, repair and modification activities for its key partners (e.g. OEMs, pool partners or repair vendors) who do not possess the necessary maintenance capabilities. This principle also extends to MROs, who sometimes require maintenance services from other MROs who, for example, is specialised in engine or landing gear maintenance. It is also possible to further segment these customers on geographic region or size of the enterprise. However, in order to maintain parsimonious and refrain from incorporating an excessive number of assumptions, the MRO Business Model Canvas only includes the distinction between aircraft operator, MRO key partners and MRO competitors.

3.3 Stress factor formulation

This paragraph first provides a justification behind the design and selection of the stress factors that were used throughout this research (**3.3.1**), which are: extent of data exposure (**3.3.2**); extent of network support (**3.3.3**); extent of regulatory support (**3.3.4**).

3.3.1 Selection and justification of the stress factors

This paragraph considers the situation where MROs adopt Blockchain as an aircraft spare part track and trace capability. As previously discussed, according to Haaker et al, stress factors are typically formulated through trend analysis and brainstorm sessions with business experts. The problem with this approach is that it introduces bias, since participants typically relate to previous experience to formulate stress factors. Additionally, Haaker et al recommends a limitation of five stress factors. For this research, initial uncertainties were based upon Blockchain limitations (Smith, 2013; Swan, 2015), which were: Blockchain privacy problem; Business Model Alignment problem; Government Regulation uncertainty. The reason why these uncertainties were chosen is because they represent a technical, societal and regulatory factor. Throughout the coding process, attention is paid to identify the presence of these uncertainties. Based on that, it was possible to reframe the uncertainties into MRO stress factors: Extent of data exposure; Extent of network support; Extent of regulatory support. This process is visually presented in the first chapter (**Figure 1**), where generation of the stress factors originate from two sources. According to Haaker et al, outcomes of each uncertainty are merely polar extremes (e.g. network support: minimum support; industry support).

3.3.2 Stress factor #1: Extent of data exposure

The first stress factor relates to the privacy risk that is introduced by Blockchain by increasing supply chain transparency. The level of transparency can relate to only exposing traceability data, or also reliability data (e.g. regulator emphasise importance of sharing reliability data). This reduced information asymmetry could have profound implications for the current MRO business model. Two outcomes for this uncertainty are:

- Exposing only non-sensitive traceability data;
- Exposing both non-sensitive traceability and sensitive reliability data.

3.3.3 Stress factor #2: Extent of network support

The second stress factor relates to the problem of business model alignment, which could induce actors to not support Blockchain. For the Blockchain to have any value, it is important that industry participants support the system. Depending on the degree of network support, the MRO business model may be affected differently when Blockchain is only used to share data between an MRO and its partners, or throughout the aviation industry when a Blockchain standard emerges. The two outcomes for this uncertainty are:

- Aircraft spare part data is shared only between an MRO and its partners;
- Aircraft spare part data is shared widespread throughout the aviation industry.

3.3.4 Stress factor #3: Extent of regulatory support

The third stress factor relates to the uncertainty regarding government regulation, which relates to the extent whether EASA and FAA would oppose Blockchain. The conservative nature of the aviation industry might incentivise these institutions to not support and mandate the use of Blockchain. The two outcomes for this uncertainty are:

- Regulatory institutions oppose the use of Blockchain technology;
- Regulatory institutions support the use of Blockchain technology.

3.4 CONCLUSION

This chapter assumed multiple roles: 1) to provide the reader with a theoretical background on Business Model Stress Test, the technique used to evaluate the MRO business model robustness; 2) to formulate and empirically validate the literature-based MRO business model; 3) to formulate stress factors against which the MRO business model will be confronted. Based on the desk research, it is possible to address the second research question:

How is it possible to systematically evaluate the robustness of MRO business models when it is confronted against Blockchain as an aircraft spare part track and trace capability?

Desk research on business model identifies Business Model Stress Test as the only academic method to systematically evaluate business model robustness in early stages of strategic formulation to cope with uncertain future scenarios. Unfortunately, this method is qualitative in nature, with no quantitative assumptions to support the research. The validity and reliability of the test therefore depend on the quality of the business model and the selected stress factors. Luckily, the method is ontology-agnostic, which means that any design method can be used to describe the business model. Since changes in aircraft spare part information exchange practices can directly or indirectly impact aircraft maintenance activities, the decision was made to focus on the MRO business model. Among the four identified business model ontologies, the decision was made to adopt the Business Model Canvas, since the model is exhaustive in covering different business model components; is applicable in any context; is easy to analyse and communicate; builds upon previous work. The figure below shows an overview of the canvas (**Figure 21**), based on paragraph 3.2.

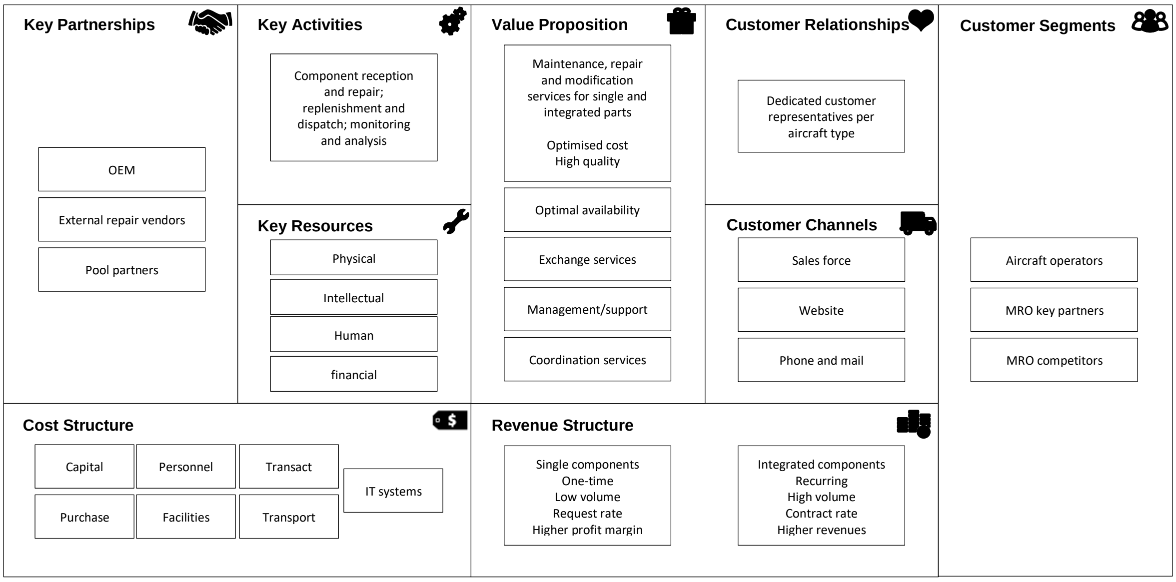

Figure 21 – MRO Business Model Canvas

As discussed in paragraph 3.3, through desk research on Blockchain and through interviews, three stress factors are formulated: extent of data exposure; extent of network support; extent of regulatory support. These factors are used to later evaluate whether the MRO business model is robust when they are exposed to these uncertainties in a Blockchain-based environment. The outcome of that part of the Business Model Stress Test is a heat map, where business model components are confronted against stress factors.

To acquire data on the relationship between Blockchain as an aircraft spare part track and trace capability and the MRO business model components, as well as data on how this impact could fluctuate when moderated by different stress factors, it is necessary to develop a research protocol. Therefore, the next chapter provides the protocol that would guide prospective researchers to execute the proposed evaluation methodology in this chapter.

4 RESEARCH PROTOCOL

The fourth chapter is dedicated to support the replicability of the research and guide any prospect researcher to acquire data on the relationship between Blockchain as an aircraft spare part track and trace capability and MRO business model components. The chapter first introduces the conceptual model, which combines relevant information from the theoretical framework and evaluation methodology to provide an overview of variables that are studied (**4.1**). Given the fact that this research incorporates both quantitative and qualitative strategies, the mixed methods approach is adopted (**4.2**). To support research replicability, data collection, data analysis and Business Model Stress Test strategies are provided (**4.3**). Finally, the chapter reflects on how the research strategies can contribute to research validity and reliability (**4.4**). Given the purpose of this chapter to support research replicability, it does not address any research questions. Additionally, this chapter is not placed before chapter 2 or 3, since chapter 4 draws upon knowledge from those chapters in order to construct a rigorous protocol.

4.1 CONCEPTUAL MODEL

A conceptual model is created to provide an overview of variables that are studied in remaining parts of this research. The selection of the variables should consider the following:

- Context: The research adopts a scenario that is theoretically constructed through chapter 2 – the application of Blockchain to track and trace aircraft spare parts.
- Unit of analysis: The research is focused on a single unit of analysis that is theoretically constructed through chapter 3 – the MRO Business Model Canvas.
- Stress factor: The research is focused on evaluating MRO business model robustness by exposing it to three stress factors: extent of data exposure; extent of network support; extent of regulatory support.
- Evaluation factor: The research is specifically focused on the ability of Blockchain to increase transparency throughout the aviation industry. There are two reasons for this decision: 1) the research problem and objective are dedicated to addressing industry transparency; 2) the premise of Blockchain as an aircraft spare part track and trace capability is to increase supply chain and ecosystem transparency.

These factors can be captured in a conceptual model that outlines how these variables are related (**Figure 22**). The purpose of this model is to immediately show the reader how the remaining parts of the research is structured. The logic of this model can be related to the very objective of this research: the necessity to evaluate the impact of Blockchain on the MRO business model and how this fluctuates when it is exposed to different stress factors.

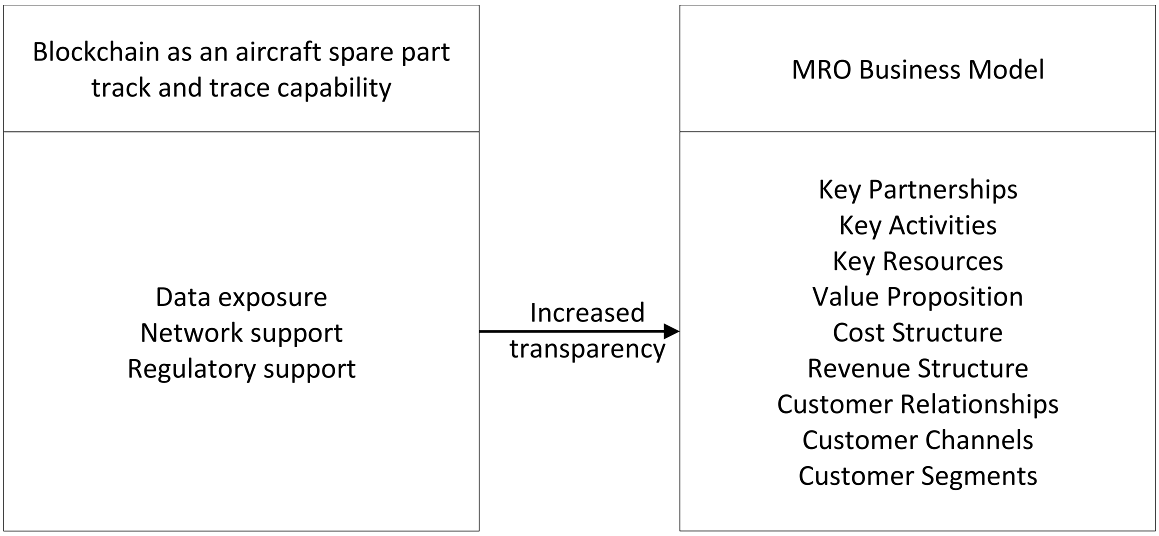

Figure 22 – Conceptual model

4.2 MIXED METHODS APPROACH

Based on requirements from the first supervisor to adopt multiple approaches to the research, namely a quantitative and qualitative approach, the nature of the research can automatically be characterised as *mixed methods* (Creswell, 2003). This methodology involves the collection, analysis and integration of both quantitative data (e.g. through surveys) and qualitative data (e.g. through interviews). This approach integrates both close-ended information that can be identified through attitude measurements (e.g. rating scales) and open-ended information result in extensive insight (e.g. words).

This approach supports the notion of triangulation by combining different data collection and analysis strategies in order to approach the main research question and phenomenon from different perspectives. This is especially useful when a researcher wishes to develop a theory and then test it. This research initially developed a hypothetical proposition that Blockchain can be used as an aircraft spare part track and trace capability in order to increase transparency throughout the aviation supply chain and ecosystem. The remainder parts of the research evaluate what this transparency would truly mean for the robustness of the MRO business model. The sequence of theoretical development and empirical evaluation supports the notion and motivation behind mixed methods.

To select a specific mixed methods design, it is necessary to evaluate the different main design types, sequences, and consider their strengths and weaknesses (**Table 7**).

Table 7 – Overview of mixed method designs (Creswell, 2003)

Type of design	Sequence	Strengths	Weaknesses
Sequential explanatory design	First quantitative, then qualitative	Easy to implement Easy to report	Substantial time
Sequential exploratory design	First qualitative, then quantitative	Easy to implement Easy to report	Substantial time
Concurrent triangulation	Qualitative/quantitative concurrently	Validated findings Less time	Requires expertise Difficult integration
Concurrent nested	Predominant method nests the other method	Validated findings Less time	Difficult integration Unequal evidence

The decision is made to adopt a *concurrent nested mixed methods design* for the following reasons:

- Given the fact that both sequential explanatory and exploratory mixed methods designs acquire different data in separate steps, it requires substantial time to complete data collection. Since this research is confined to a timespan of 5 months, these two mixed methods designs are not feasible.
- Concurrent triangulation mixed methods design is recommended for researchers who have a great amount of expertise, since they can draw upon their experience to adequately use and integrate two separate methods at the same time.
- A more feasible approach is the concurrent nested mixed methods, which requires less time and experience compared to the alternative mixed methods designs.

Through the concurrent nested mixed methods design, focus is provided on one type of method (e.g. qualitative) and then embeds the other method (e.g. quantitative). This research primarily relies upon qualitative interview data and embeds quantitative survey data. This provides broader and in-depth perspectives on the impact of Blockchain on the MRO business model by identifying the impact and quantifying the interviewee perspectives. As a result, the study offsets the disadvantages of both qualitative and quantitative data. However, if there are discrepancies between the two data types, then it could affect the validity of the results. To prevent this risk, it is necessary to design and evaluate appropriate research strategies that secure the validity and reliability of the research.

4.3 RESEARCH STRATEGY

This paragraph attempts to secure the validity and reliability of the research by developing data collection strategies (**4.3.1**), data analysis strategies (**4.1.2**), Business Model Stress Test strategies (**4.1.3**) and Business Model Stress Test strategies (**4.1.3**)

4.3.1 Data collection strategy

The data collection strategy is characterised by a few key elements: 1) sampling strategy; 2) qualitative (interview) data collection strategy; 3) quantitative (survey) data collection strategy.

Sampling strategy

An important hallmark of mixed methods is that it should draw upon multiple sources of evidence, whether from quantitative or qualitative nature (Creswell, 2003). This research relies upon four sources to support evidence building processes: 1) documentation to develop the MRO business model and case; 2) interviews and transcripts to evaluate the perception of change in the model and refine the model; 3) quantitative data from surveys at the end of each interview to quantify the perception; 4) a business model stress test workshop after evaluating the impact of Blockchain on the MRO business model.

As it is immediately noticeable, each of these sources are focused on the same unit of analysis: the MRO business model. Data triangulation increases the construct validity of the findings, since different data points provide the same information (Yin, 2013). Initially, the data collection procedure is fundamentally approached qualitatively, since the purpose of the empirical part of the research is to acquire and discuss different industry perspectives and expertise. Through semi-structured guided interviews, descriptive knowledge is acquired on elements and themes that affect the MRO business model. The interviews end with a survey through which the interviewee quantifies his/her perception on a scale.

Since the quality of the Business Model Stress Test depends on the knowledgeability of the respondents, it is necessary to choose the samples strategically rather than randomly (Yin, 2013; Saunders, Lewis, & Thornhill, 2007; Sekaran & Bougie, 2010). Unfortunately, this means that the external validity of this research is violated in order to maintain the construct validity (Yin, 2013). Additionally, intersubjectivity is introduced, since participants rely upon their own experiences to determine whether the impact of Blockchain on a specific business model component is positive, negative or neutral. To minimise the potential presence of bias or subjectivity, the research acquires data from different perspectives, enterprises and expertise (Verschuren & Doorewaard, 2010). This means that it is necessary to identify individuals within the consulting or aviation industry that possesses Blockchain or aircraft pare part management expertise (**Table 8**).

The volume of data should be uniformly distributed among these elements, which can prove a real practical challenge. The perspectives have a different number of participating enterprises. Additionally, per participating enterprise it is challenging to engage an equal number of individuals. However, it is important to ensure equal representation of both perspectives. The first perspective is provided by two consulting firms, with each four interview participants. The second perspective is provided by an airline-owned MRO, and independent MRO and an OEM, which would cover the main parts of the aviation supply chain. Four participants are involved from the airline-owned MRO and two from both the independent MRO and the OEM.

Table 8 – Interviewee participation list

	Function	Expertise
Consulting 1	Management Consulting Analyst	Spare part management
	Management Consultant	Spare part management
	Technology Architecture Delivery Senior Manager	Blockchain technology
	Technology Consulting Senior Manager	Overall MRO industry
Consulting 2	Senior Management Consulting Executive	Overall MRO industry
	Management Consulting Principal Director	Overall MRO industry
	Management Consulting Executive	Overall MRO industry
	Management Consulting Senior Manager	Overall MRO industry
MRO 1	Enterprise Architect	Blockchain and MRO
	Blockchain Program Manager	Blockchain technology
	B787 Supply Chain Specialist	Supply Chain expertise
	Change Manager	Blockchain and MRO
MRO 2	Maintenance Manager	Overall MRO industry
	Maintenance Controller	Overall MRO industry
OEM	Senior System Engineer	Blockchain and MRO
	Procurement Director	Supply Chain expertise

Qualitative data collection strategy

The qualitative nature of this research necessitates the adoption of interview data collection methodologies (Yin, 2013; Saunders, Lewis, & Thornhill, 2007; Sekaran & Bougie, 2010). The purpose of the interview is to address the third research question:

How does Blockchain as an aircraft spare part track and trace capability impact the MRO business model?

The interviews are guided by the conceptual model that is presented in paragraph 4.1. The interviewees are first introduced to the business context (Blockchain as an aircraft spare part track and trace capability) and guided through the unit of analysis (MRO business model). Despite this guidance, the interviews remain semi-structured in nature, since the interviewees are encouraged to remain flexible in their responses (Bryman, 1989). Once they are appropriately aware of the purpose of the context and business model, it is possible to kick-start the interview with a question, such as: *Considering the business context we focus on, how do you think Blockchain as an aircraft spare part track and trace capability could affect the MRO key partnerships?*

To evaluate the impact of Blockchain as an aircraft spare part track and trace capability on the MRO business model, the literature-based logic model is focused on the nine business model components, which act as the foundation for key themes and questions raised throughout the interviews. These themes are: 1) key partnerships, 2) key activities, 3) key resources, 4) value proposition, 5) cost structure, 6) revenue structure, 7) customer relationships, 8) customer channels, 9) customer segments. A few important elements of the interview protocol include:

- Awareness generation: Interviewees are informed on the purpose of the research, the content of the interview and the intended use of the data.
- Privacy protection: Interviewees are anonymised and sensitive data or knowledge is filtered throughout the collection process.
- Pre-interview consent: Interviewees are asked permission to record audio of the discussion.
- Post-interview review: Interviewees are sent a document of the interview transcript in English, where sensitive information is filtered out. Interviewees may modify or correct this transcription. Additionally, interviewees are sent the final results of the research, either in form of this thesis or the paper published by Accenture.

Quantitative data collection strategy

A potential second mitigation solution could not only assure that intersubjectivity bias is reduced, but also could attempt to improve the generalisability of the results (Sekaran & Bougie, 2010). This is reflected by the decision to include a survey in the research methodology, where the qualitative perception of the interviewee is quantified. The problem is that it is difficult to send out this survey to a general public (e.g. the department of Accenture Strategy) to evaluate this impact, due to the very specific scope of the research and the novelty of Blockchain within MRO. Even though the data would be more generalisable and reliable, the validity of the data is questionable since participants might have little experience with MRO operations (Verschuren & Doorewaard, 2010). Therefore, the research limits the distribution of the surveys to only the knowledgeable interviewees, who at the end of the interview evaluate their opinion on a five-point itemised rating scale. This also assures that the business model can be constructed more objectively, since the colouring codes are determined through an analysis of quantitative data that is supported by qualitative arguments. The interviewees are presented with the following short survey that quantitatively captures their perspectives:

How do you think Blockchain as an aircraft spare part capability could impact the MRO business model?					
Component	**Very poor (1)**	**Poor (2)**	**Neutral (3)**	**Good (4)**	**Excellent (5)**
Key partnerships	0	0	0	0	0
Key activities	0	0	0	0	0
Key resources	0	0	0	0	0
Value proposition	0	0	0	0	0
Cost structure	0	0	0	0	0
Revenue structure	0	0	0	0	0
Customer relationships	0	0	0	0	0
Customer channels	0	0	0	0	0
Customer segments	0	0	0	0	0

During the introduction of the interview, interviewees are presented with the scale and its purpose to quantify their perspectives. It is understandable if the interviewee has the concern that they could not address this survey. This is why this table should be shown at the end of the discussion, after the interview process. This allows interviewees to reflect upon their statements, which helps them easily determine whether they consider the impact of Blockchain on an MRO business model component as negative (1/2), neutral (3) or positive (4/5). This part of the discussion can be kick-started with a question, such as: *Based on the interview, we notice that you have a certain position regarding the impact of Blockchain on the MRO business model. Could you, based on your previous explanations, try to quantify your opinion? How would you evaluate your opinion and why?*

By adopting a quantitative assumption and approach to business model generation, the Business Model Stress Test model is extended (Haaker, Bouwman, Janssen, & de Reuver, 2017). Thus, the final step is to correlate the itemised rating scale with the model's colouring codes. According to the model, the business model is coloured through four categories, with no distinction between business model components that may receive some or extensive positive impact. Therefore, the following adjusted scale is proposed:

- Excellent (5) - Green: The component is feasible and viable with high positive impact.
- Good (4) – Lime: The component is feasible and viable with positive impact.
- Neutral (3) - Grey: The component is not affected in any way (or effects outweigh).
- Poor (2) - Orange: The component is no longer viable and requires revision.
- Very poor (1) - Red: The component is no longer feasible.

4.3.2 Data analysis strategy

The data analysis strategy is characterised by a few key elements: 1) transcription strategy; 2) coding strategy; 3) quantitative analysis strategy.

Transcription strategy

The interviews are recorded and conducted face-to-face or through videoconferencing platforms, such as Skype for business. The audio recording of each interview is appropriately managed and categorised. The benefit of adopting the conceptual model in the research strategy is that the interviews, despite its semi-structured nature, consistently cluster the main themes together. This assures that the audio files can be transcribed almost verbatim, where only off-topic or sensitive discussion points are filtered out. This contributes to the reliability of the research, since the inclusion of these transcripts in the appendix allow future researchers to evaluate the findings and conclusions of this study. The transcription process is manual, where transcription software (e.g. InqScribe) allow control over the timing of the audio file.

Coding strategy

Once the interview data is transcribed, it is necessary to engage in coding procedures where specific passages of the transcription are highlighted with certain colours, labelled with a meaningful code and categorised into groups that combined form an overarching thematic category. This process is facilitated by a qualitative data analytics software called MAXQDA, which can be reviewed by future researchers and reviewers. An important point to consider is that the interviews were designed with the idea to evaluate the business model, which is why this logic model further strengthens the internal validity of the research. Furthermore, it is possible that specific codes can impact more than one business model component. These complex interrelations can be derived from thematic analysis, where specific codes are correlated with one or multiple business model components (Attride-Stirling, 2001). Furthermore, it may be possible that additional thematic categories can be identified that raise discussion beyond the impact of Blockchain on the MRO business model. When these thematic categories are consistently identified, it is necessary to group them during the coding process and present them as additional research results (presented in 5.3).

Quantitative analysis strategy

Once the survey data is collected, it will be clustered, categorised and managed through an Excel document. The document will cluster the survey data per interview and business model component, categorised under its respective enterprise. With data of the respondent evaluation, histograms are developed for each business model component. Additionally, average scores are calculated that will be used for determining the overall business model impact. Furthermore, quantitative data is derived from MAXQDA that highlights the importance of each discussed theme, which will also be captured in histograms.

4.3.3 Business Model Stress Test strategy

First, the MRO business model and stress factors are defined upfront through desk research and evaluated with Accenture employees. Then, interviewees were approached to evaluate the impact of Blockchain on the MRO business model through interviews and surveys (presented in 5.1). After the data is processed, the impact and stress factors should be presented through a group interview towards industry experts. Through this workshop, the group is presented with a heat map and they can use post-it notes to discuss how the impact changes when it is subject to different stress factors (e.g. high data exposure; low industry support; opposing regulation). The purpose of the workshop is too address the fourth research question (presented in 5.2):

How robust are MRO business models when it is confronted against Blockchain as an aircraft spare part track and trace capability?

4.4 RESEARCH VALIDITY AND RELIABILITY

This paragraph reflects on the ability of the research strategies to safeguard the construct validity (**4.4.1**), internal validity (**4.4.2**), external validity (**4.4.3**) and reliability (**4.4.4**) of this research.

4.4.1 Construct validity

Construct validity relates to establishing correct operational measures for the concepts that are being measured (Yin, 2013). To safeguard the construct validity, the research design incorporates multiple sources of evidences in order to encourage a convergent line of inquiry. Triangulation plays an important role in this research by acquiring insight from documents, interviews and surveys from both a consulting and industry perspective. Furthermore, the findings and insight of this research is reflected in a paper that is published by Accenture. This paper will be peer-reviewed by industry and Blockchain key stakeholders and informants. This feedback is used to improve the quality of this research.

4.4.2 Internal validity

Internal validity relates to establishing a causal relationship, where certain conditions are shown to lead to other conditions (Yin, 2013). To safeguard the internal validity, the research design incorporates the MRO business model logic in order to provide structure to the overall analysis. This process is guided by Business Model Stress Test, which is focused on sub-view and pattern analysis in order to evaluate the robustness of this model. Unfortunately, since Business Model Stress Test is the only methodology that evaluates the robustness of these models, it is difficult to address the results through rival theories. However, previous literature on aircraft spare part management and Blockchain is used for explanation building.

4.4.3 External validity

External validity relates to the extent to which the results can be analytically generalised to theoretical propositions, results of the broader research domain or populations (Yin, 2013). To safeguard the external validity, the research design focused on sound replication logic through the conceptual model and sampling strategy. The emphasis is put on theoretical replicability, since this research incorporates theory on aircraft spare part management, Blockchain technology and business models in order to construct the business case and unit of analysis. It is debatable to what extent a research with under 30 participants could result in generalisable results. However, an attempt is made to generalise the results of the qualitative research by supporting it with quantitative assumptions.

4.4.4 Reliability

Reliability relates to demonstrating the ability that the operations of a research can be repeated with the same results (Yin, 2013). To safeguard the reliability, the research design incorporates a research protocol that operationalises the research strategy and guides the investigator in collecting and analysing the data. Furthermore, a database is maintained of all interview records and transcriptions. The transcriptions are included as raw data in this report, which allows the reader to evaluate the reliability of the conclusion. Furthermore, since these transcriptions are also coded, critical readers can reflect upon the code through MAXQDA.

5 RESULTS

The fifth chapter presents the qualitative interview and quantitative survey results from sixteen interviews in three parts. The first part of the results focused on the impact of Blockchain as an aircraft spare part track and trace capability on the MRO business model. (**5.1**). The second part of the results focused on the robustness of the MRO business model when it is confronted against different stress factors (**5.2**). The third part of the results focused on the feasibility of the Aviation Blockchain consortium, since this is considered important by interviewees (**5.3**).

Each part of the result is structured consistently: 1) introductory paragraph on the content of the section; 2) key message; 3) exclusive to paragraph 5.1: description of the section structure. At the end of each paragraph, a conclusion is provided to address each respective research question. The next chapter provides an overarching conclusion of the entire research.

Finally, the figures and tables of this chapter follow a specific colouring code, which is applicable through the entirety of chapter 5:

- Excellent (5) - Green: The component is feasible and viable with high positive impact.
- Good (4) – Lime: The component is feasible and viable with positive impact.
- Neutral (3) - Grey: The component is not affected in any way (or effects outweigh).
- Poor (2) - Orange: The component is no longer viable and requires revision.
- Very poor (1) - Red: The component is no longer feasible.

5.1 STRATEGIC IMPACT OF BLOCKCHAIN ON THE MRO BUSINESS MODEL

Introduction: The first part of the results focused on the impact of Blockchain as an aircraft spare part track and trace capability on the MRO business model. These results were acquired by coding the interviews and analysing the surveys that were given during these interviews. This paragraph frames and synergises the interview data to capture the impact on 27 strategic areas of nine MRO business model components: key partnerships (**5.1.1**), key activities (**5.1.2**), key resources (**5.1.3**), value proposition (**5.1.4**), cost structure (**5.1.5**), revenue structure (**5.1.6**), customer relationships (**5.1.7**), customer channels (**5.1.8**) and customer segments (**5.1.9**). these results provide answer to the third research question (**5.1.10**):

How does Blockchain as an aircraft spare part track and trace capability impact the MRO business model?

Key message: Based on quantitative data from a total of sixteen consulting and industry participants, it is possible to conclude that the average impact of Blockchain on the MRO business model is considered positive. It is assumed that the average impact is considered positive if it exceeds a threshold of 3,5 (**Figure 23**). The logic behind this assumption is that most average scores range between 3 and 4, with 3 valued as a neutral and 4 as a positive impact. A decision was made to evaluate the impact as positive when it passes the average of the two values. However, a more critical reviewer or researcher could lower the threshold.

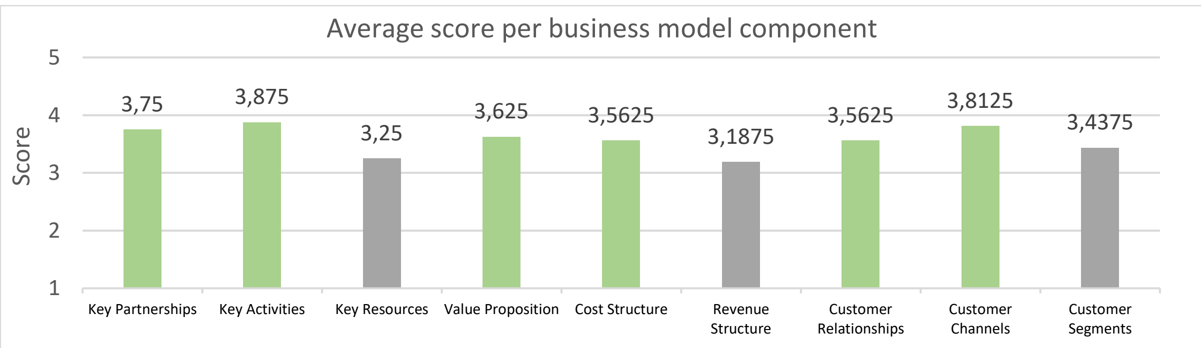

Figure 23 – Quantitative overview: impact of Blockchain on the MRO business model

Unfortunately, the quantitative results do not provide sufficient insight on why and how Blockchain could have a certain impact on MRO business model components. It is necessary to dive into the detailed qualitative and quantitative results per business model component.

Structure: Each discussion maintains a consistent structure: 1) key message about the overall consensus and the quantitative evaluation table supporting the consensus; 2) identification of key themes considered important by interviewees; 3) summary of the qualitative discussions that focus on the key themes; 4) fully discussed key themes to justify the key message.

5.1.1 Strategic impact of Blockchain on key partnerships

Key message: There is consensus among both consulting and industry participants that Blockchain as an aircraft spare part track and trace capability could positively impact MRO key partnerships (**Table 9**).

Table 9 – Key Partnerships: respondent evaluation

	Consulting 1	Consulting 2	MRO 1	MRO 2	OEM	Total
5: Excellent	0	0	1 (6%)	0	0	**1 (6%)**
4: Good	4 (25%)	1 (6%)	2 (13%)	2 (13%)	1 (6%)	**10 (63%)**
3: Neutral	0	3 (19%)	1 (6%)	0	1 (6%)	**5 (31%)**
2: Poor	0	0	0	0	0	**0**
1: Very poor	0	0	0	0	0	**0**
Total	4	4	4	2	2	16

Key theme identification: To understand why respondents are positive about the impact of Blockchain on the MRO key partnerships, the discussion is broken down into three key themes considered important by them (**Table 10**): 1) aircraft spare part information and asset exchange (**A1**); 2) aviation supply chain and ecosystem trust (**A2**); 3) aircraft spare part intellectual property control (**A3**).

Table 10 – Key Partnerships: frequency of each addressed theme

	Consulting 1	Consulting 2	MRO 1	MRO 2	OEM	Total
A1: Exchange	12 (21%)	8 (14%)	2 (3%)	6 (10%)	4 (7%)	**32 (55%)**
A2: Trust	8 (14%)	1 (2%)	7(12%)	3 (5%)	4 (7%)	**23 (40%)**
A3: IP control	0	2 (3%)	0	0	1(2%)	**3 (5%)**
Total	20 (34%)	11 (19%)	9 (16%)	9 (16%)	9 (16%)	58

Summary: Blockchain is believed to be able to support the cooperation and trust between MROs, OEMs and operators through improved aircraft spare part information and asset exchange activities. This is possible since component data would be exchanged and synchronised over different IT systems and databases, allowing MROs to obtain a holistic view of the ecosystem. As a result, MROs become more trusted as they operate with legitimate components that contain back-to-birth dataset and they become more confident in the legitimacy of the components that they purchase. However, since a certain degree of trust is required to operate in the MRO industry and establish Blockchain, the improved trust perception might only be marginal. The risk of Blockchain-based aircraft spare part management is that if sensitive component data exchange leaks, it could deteriorate the partnerships throughout the ecosystem. This shows that full transparency is questionable, especially since the different parties might not want to share component data with potential opportunists. This might hinder parties from having a certain degree of confidence in the data integrity, which is necessary if the industry wishes to use Blockchain as a component data sharing platform. Additionally, Blockchain can facilitate interaction between independent MROs and OEMs that currently try to access the component IP of the opposite party. However, OEMs that operate in the component aftermarket are incentivised to maintain component IP control and limit competitors from having access to the components through Blockchain.

A1 – Aircraft spare part information and asset exchange

Currently, information exchange is seen as a labour-intensive process, since a lot of manual labour is required to transfer data from one IT system to another (*Consulting 1 – Appendix I*). This is primarily due to lack of IT standards since each ecosystem participant uses different IT systems and databases to record and process component data (*Consulting 1 – Appendix I, II, IV*). The problem intensifies when trivial component data must be manually shared between an OEM, MRO and operator, which is subject to human error (*Consulting 1 – Appendix I*). To acquire insight on what parts are located in what part of the aircraft, MROs engage in extensive interaction with OEMs, since they are obligated to fully understand the aircraft configuration (*Consulting 1 – Appendix I; MRO 2 – Appendix XIV*). Depending on their costs and capabilities, MROs sometimes outsource maintenance or acquire new customers, through which a lot of information exchange occurs (*Consulting 1 – Appendix II*). Aircraft spare part management is seen as a typical example where it is necessary to search cooperation between MROs, OEMs and operators, since all participants maintain their own copies of component data and it is important to assure that these data match (*Consulting 1 – Appendix IV*). Blockchain is in a position to help MROs support this cooperation and improve information and asset exchange activities (*Consulting 1 – Appendix I, II, III, IV*).

The first example of how Blockchain could contribute to information exchange activities is for spare part pool participants that requires data on the shared components (*Consulting 1 – Appendix I; OEM – Appendix XV*). The second example relates to MROs who look for data on deployed aircraft and components, which is especially relevant when they will retrieve these assets from their clients (*Consulting 1 – Appendix II; Consulting 2 – Appendix VII*). The third example relates to MROs reporting component maintenance data to regulatory authorities through Blockchain (*Consulting 2 – Appendix VII, VIII*). Currently component exchange occurs on paper with Form 1's and with Blockchain it is digitally updated real-time in a distributed database (*MRO 2 – Appendix XIII, XIV*). Example of how Blockchain could contribute to asset exchange activities relates to automating the exchange process with smart contracts (*MRO 1 – Appendix XI*).

There are scenarios in which Blockchain-based information exchange might actually deteriorate the MRO relationships, for example when the Blockchain solution is not secure enough and leaks sensitive spare part data (*Consulting 1 – Appendix I*). Furthermore, MROs that use the Blockchain to obtain a holistic view of the ecosystem might conclude that components from a specific area code are not reliable and re-evaluate their relationship with component providers from those areas (*Consulting 1 – Appendix III*). However, this holistic view imposes a major challenge for Blockchain-based aircraft spare part information and asset exchange: the extent to which data is exchanged (*Consulting 2 – Appendix VIII; MRO 1 – Appendix X; MRO 2 – Appendix XIV*). Today, the MRO industry is considered fragmented, where each participant is siloed in their own part of the maintenance process and component lifecycle (*Consulting 2 – Appendix VI; OEM – Appendix XVI*). Therefore, the ability of Blockchain to control data accessibility is important, since it is not desirable to share sensitive component data with competitors (*Consulting 2 – Appendix VIII; MRO 2 – Appendix XIII, XIV*).

Even though this is one reason why full component transparency may not possible in the short-term future, MROs already exchange component data with preferred partners in a rudimentary way (*Consulting 2 – Appendix VIII*). When an MRO receives a component that must be installed on an aircraft, they must be entirely sure that important component data (e.g. number of cycles) is correct, since this data could impact the reliability of aircraft maintenance (*Consulting 1 – Appendix IV; Consulting 2 – Appendix VIII*). For that purpose, it is important for MROs to optimally exchange its data with aircraft operators, who is performing the day-to-day aircraft operations (*Consulting 2 – Appendix VIII; OEM – Appendix XVI*). A Blockchain platform can help these participants to share the data, but it remains a question to what extent these actors are actually willing to share their data (*MRO 1 – Appendix X*).

A2 – Aviation supply chain and ecosystem trust

MROs and operators face the problem of respectively maximising component utilisation and aircraft availability, which they try to optimise in a distrusted relationship (*OEM – Appendix XV*). For this relationship, Blockchain can be used to confirm and track the history of rotable aircraft spare parts with shared real-time back-to-birth component data set (*Consulting 1 – Appendix III; MRO 1 – Appendix X; OEM – Appendix XV*). A degree of trust is required in order to establish the Blockchain, since all parties will have insight in the data shared by each other (*MRO 1 – Appendix XI; MRO 2 – Appendix XIV*). Once the necessary trust is developed, Blockchain can support the incentive alignment model by helping MROs and operators optimise its problem set (*Consulting 1 – Appendix III; OEM – Appendix XVI*).

MROs would be encouraged to become transparent through the Blockchain, since they can show to the entire network that they can be trusted since they operate only with legitimate aircraft spare parts (*Consulting 1 – Appendix III*). Suppliers that provide counterfeit components to the market will be caught early and be rejected from the network (*MRO 2 – Appendix XIV*). MROs who have been in the network longer than their competitors may be perceived more trustworthy by their partners (*Consulting 1 – Appendix III*). Not only will MROs be trusted more by the network, they are also more confident that the components they purchase from other Blockchain participants is legitimate (*Consulting 1 – Appendix IV*). Those who are not willing to join Blockchain may be perceived untrustworthy (*MRO 1 – Appendix X*).

Until confidence increases in the integrity of the component data, the Blockchain will be considered as an application that can be used to cross-check component data (*MRO 1 – Appendix X*). When confidence emerges, the Blockchain can be seen as a data sharing platform for maintenance across the MRO industry through which these participants interact less by mail and phone (*MRO 1 – Appendix X, XI*). Despite these claims, it is important to understand that the cost competitive MRO industry already expects a certain degree of trustworthiness (*Consulting 2 – Appendix VI*). This is due to the sensitive nature of aircraft maintenance, since clients trust MROs with the safety of their aircraft (*Consulting 1 – Appendix IV; Consulting 2 – Appendix VI*). Currently, trust is defined through the approved supply list, which Blockchain might invalidate since only trusted and proven parties participate in the network (*MRO 2 – Appendix XIV*). Blockchain could only improve the trustworthiness of an MRO marginally, since clients consider also other factors (e.g. facilities and reputation) (*Consulting 2 – Appendix VI*).

A3 – Aircraft spare part Intellectual Property control

The uncertainty of the extent to which data is shared through the Blockchain shows the concern between the MRO and OEM: the licensed ability to access intellectual properties (*OEM – Appendix XV*). As maintenance is commoditized, OEMs are incentivised to control the aftermarket of their components (*Consulting 2 – Appendix VI*). OEMs that try to access the aftermarket face the problem of data accessibility of externally manufactured valuable IPs (e.g. avionics, APU, engine) that are part of their manufactured aircraft (*Consulting 2 – Appendix VI*). As a result, OEMs have taken steps to limit the amount of work that MROs can do on their IP and attain control over the market, which makes it difficult for independent MROs to serve different spare part segments (*Consulting 2 – Appendix VI*). As these OEMs start to behave as independent MROs, OEMs are put in a unique position in the aviation ecosystem since independent MROs start considering them as competitors (*Consulting 2 – Appendix VI*). However, airline-controlled MROs might have more power to access these IPs, since OEMs want to sell their products to aircraft operators (*Consulting 2 – Appendix VI*). Therefore, independent MROs that compete in these segments accept technologies that would provide them improved access to the OEM's IP, which can be facilitated by Blockchain (*Consulting 2 – Appendix VI*). With the desire to control IP, it is questionable whether the OEM is actually incentivised to engage in Blockchain with MROs (*Consulting 2 – Appendix VI*). From an OEM perspective, they would use Blockchain in order to access IPs that are utilised by MROs (*OEM - Appendix XV*).

5.1.2 Strategic impact of Blockchain on key activities

Key message: There is consensus among both consulting and industry participants that Blockchain as an aircraft spare part track and trace capability could positively impact MRO key activities (**Table 11**).

Table 11 – Key Activities: respondent evaluation

	Consulting 1	Consulting 2	MRO 1	MRO 2	OEM	Total
5: Excellent	0	0	0	1 (6%)	1 (6%)	2 (12%)
4: Good	3 (19%)	3 (19%)	2 (13%)	1 (6%)	1 (6%)	10 (63%)
3: Neutral	1 (6%)	1 (6%)	2 (13%)	0	0	4 (25%)
2: Poor	0	0	0	0	0	0
1: Very poor	0	0	0	0	0	0
Total	4	4	4	2	2	16

Key theme identification: To understand why respondents are positive about the impact of Blockchain on the MRO key activities, the discussion is broken down into seven key themes considered important by them (**Table 12**): 1) Regulatory Compliance (**B1**); 2) Predictive Maintenance (**B2**); 3) Inventory Management (**B3**); 4) Component Sourcing (**B4**); 5) Quality Assurance (**B5**); 6) Maintenance Troubleshooting (**B6**); 5) Maintenance Execution (**B7**).

Table 12 – Key Activities: frequency of each addressed theme

	Consulting 1	Consulting 2	MRO 1	MRO 2	OEM	Total
B1: Regulate	10 (9%)	1 (1%)	0	4 (4%)	1 (1%)	16 (15%)
B2: Prediction	5 (5%)	2 (2%)	3 (3%)	9 (8%)	3 (3%)	22 (21%)
B3: Inventory	4 (4%)	7 (7%)	5 (5%)	3 (3%)	2 (2%)	21 (20%)
B4: Sourcing	14 (13%)	5 (5%)	1 (1%)	2 (2%)	3 (3%)	25 (24%)
B5: QA	0	1 (1%)	1 (1%)	4 (4%)	0	6 (6%)
B6: Trouble	1 (1%)	0	1 (1%)	3 (3%)	0	5 (4%)
B7: Execution	1 (1%)	4 (4%)	2 (2%)	2 (2%)	2 (2%)	11 (10%)
Total	35 (33%)	20 (19%)	13 (12%)	27 (25%)	11 (10%)	106

Summary: Blockchain can streamline the infrastructure that allow MROs and their Continuing Airworthiness Management Organisations to meet their regulatory requirements through the combination of cryptographic security, component visibility and smart contracts. Theoretically, Blockchain could connect with historically clean big data from component IoT devices and predict maintenance. If parties are willing to share component behaviour data (e.g. temperature, pressure) through the Blockchain, MROs could improve their predictive analytics by drawing upon reliability data of a global pool of spare parts. However, it is questionable whether this data will end up on the Blockchain, since MROs acquire their value from their predictive maintenance capabilities. Furthermore, it is considered financially and technically undesirable to include all sensitive component behaviour data of all components on the Blockchain, since the Blockchain cannot be scaled to support that frequency of component data exchange. In a hypothetical scenario where this is possible, MROs can indirectly reduce inventory risk through real-time data on global stock availability. Regardless of whether component behaviour data is shared, Blockchain can act as a back-office tool that allow seamless component payment and contracting processes. This premise gives MROs the flexibility to analytically source high-quality components from locations that were previously not considered. Furthermore, by acting as an aircraft spare part track and trace capability, Blockchain can provide increased accessibility to data of serial numbered components. This can help MROs 1) to reduce paperwork associated with Quality Assurance, where they must state whether the component meets aircraft configuration and regulation criteria; 2) minimise unnecessary component replacements by improving maintenance troubleshooting. Despite potential improvements in a majority of maintenance related activities, it is clear that Blockchain will not impact the core of labour-intensive component maintenance activities.

B1 – Regulatory Compliance
MROs are guided by airworthiness directives that state when aircraft spare parts must be modified or maintained (*Consulting 1 – Appendix I*). The installation of these parts must be recorded in maintenance systems that check the compliancy of an aircraft configuration (*Consulting 1 – Appendix I*). As these components are installed, it is important to notify authorities that the aircraft spare parts operate within specified limits (*Consulting 1 – Appendix IV*). Continuing Airworthiness Management Organisations (CAMO) are entities within the MRO organisation that ensure that the aircraft complies with these regulations (*Consulting 1 – Appendix IV*). Once the authority audits and deems the MRO compliant, they grant the MRO the ability to issue EASA or FAA certificates (*Consulting 2 – Appendix V*). The value proposition of Blockchain can be directed to the CAMO by providing more component data (*Consulting 1 – Appendix IV; MRO 2 – Appendix XIII*) and to the overall MRO by helping them acquire parts faster as they have increased data transparency on which parts are located at which partners (*Consulting 1 – Appendix I, II*). With Blockchain, the combination of cryptographic security, component visibility and smart contracts would streamline the infrastructure that allow MROs to meet their regulatory requirements (*OEM – Appendix XVI*).

However, a major problem is that no commercial or enterprise solution exists to allow the storage of large documents (e.g. airworthiness certificates) on the Blockchain (*Consulting 1 – Appendix III*). This is a problem for an MRO business network that must enforce the presence of these certificates when requested by a regulator (*Consulting 1 – Appendix III*). If it is possible to store these attachments (e.g. manual) on the Blockchain, it is possible to include the revision control of these documentation, which is a task that can take up to a day (*MRO 2 – Appendix XIII*). For CAMOs to derive any value from Blockchain, it is necessary for parties to share data on 1) what type of maintenance or modification occurred on the components and 2) how much cycles these components are subject to (*Consulting 1 – Appendix IV*). If everyone couples their data, it is possible to release the aircraft to service by plugging Blockchain into the Part M configuration data without the engineer that must check whether the inspection must be changed (*MRO 2 – Appendix XIII*).

B2 – Predictive Maintenance
The aviation industry always focused on reliability engineering in order to improve technical dispatch reliability through predictive maintenance (*Consulting 2 – Appendix V*). Predictive maintenance is an area through which component data is used in order to improve maintenance decisioning and execution (*Consulting 1 – Appendix II*). When this data is not correct, MROs might do component maintenance too late as these components might already exceed the cycles as specified by the maintenance manuals (*Consulting 1 – Appendix IV*). A majority of the data is received from the components itself, which is why it may be possible to find a connection between Blockchain and historically clean Big Data from component IoT sensors (*Consulting 1 – Appendix II; MRO 2 – Appendix XIV*).

The ability to improve predictive maintenance depends on the data that is put on the Blockchain (*MRO 1 – Appendix X*). If Blockchain is used to only track aircraft spare parts, it will not contribute to predictive maintenance (*MRO 1 – Appendix X; MRO 2 – Appendix XIV*). Others share the sentiment that there might be no direct relationship between Blockchain and predictive maintenance (*Consulting 1 – Appendix IV*). Only if Blockchain presents more component data (e.g. engine behaviour) from all parties, and not only their own aircraft, it is possible to develop new predictive maintenance models and plan on a more discreet level (*MRO 1 – Appendix IX, X, XI; OEM – Appendix XV, XVI*). In that situation, MROs could improve predictive analytics by drawing upon reliability data for a global pool, rather than only its own pool of spare parts (*Consulting 2 – Appendix VII*). The data allows MROs to more easily identify trends on the components (e.g. Mean Time to Failure, removal, etc.) (*MRO 2 – Appendix XIII*). However, it is necessary to develop the necessary resources (e.g. converter or translator) that allow MROs to acquire reliability data through Blockchain (*MRO 2 – Appendix XIII, XIV*).

However, there is justified doubt that the component sensor data will end up in the Blockchain, since MROs acquire their value from their predictive maintenance capabilities (*Consulting 1 – Appendix IV; MRO 1 – Appendix XI; MRO 2 – Appendix XIII*). Furthermore, it is questionable whether it is financially and technically desirable to include all sensitive component data (e.g. temperature) of all components on the Blockchain (*Consulting 1 – Appendix IV*). The major reasons are: 1) Blockchain cannot be scaled to support that frequency of component data exchange; 2) MROs cannot act upon trivial component data alone (*Consulting 1 – Appendix IV*).

B3 – Inventory Management

MROs face the continuous challenge of inventory stock optimisation: understocked inventory might adversely impact the component availability; overstocked inventory might adversely impact the capital costs (*Consulting 1 – Appendix IV*). They would be able to reduce their stock and optimise inventory management if they have improved insight on the quantity and location of each spare part (*Consulting 1 – Appendix II*). However, optimising spare part inventories is something that can be improved by predictive maintenance, not directly by Blockchain (*Consulting 1 – Appendix IV; MRO 2 – Appendix XIV*). Where Blockchain merely provides the information of these components, inventory management relates to developing optimisation models with historical data to predict when and which components must be stocked (*Consulting 1 – Appendix IV; MRO 1 – Appendix XI*). If an MRO already poorly manages it supply chain, they are unlikely to improve their inventory management through Blockchain (*Consulting 2 – Appendix VI*). However, the prospect of obtaining a global view on the location of all spare parts through Blockchain give MROs the opportunity to reduce their inventory risk (*Consulting 2 – Appendix VII; OEM – Appendix XV, XVI*). At least MROs and operators are incentivised to share data on component availability, since it maps those who are in need of components (*Consulting 2 – Appendix VIII; MRO 1 – Appendix IX; MRO 2 – Appendix XIII, XIV*). The presence of real-time worldwide data on stock availability benefits the operator in terms of component availability and the MRO in terms of maintenance support, which comes at the expense of OEMs since ecosystem participants reduce the overall component usage (*Consulting 2 – Appendix VIII; MRO 1 – Appendix X*). However, there is doubt that component availability data will end up in the Blockchain (*MRO 1 – Appendix X*).

B4 – Component Sourcing

One enormous task MROs face is to form an opinion about the spare parts it receives (e.g. configuration slots, maintenance requirements), which drives component sourcing and purchase strategies (*Consulting 1 – Appendix I*). Blockchain could contribute to source location strategies by providing MROs with the intelligence on the location of each component that has clean historical records (*Consulting 1 – Appendix I, III, IV; MRO 2 – Appendix XIII*). Blockchain could contribute to component purchase activities by providing MROs with a back-office tool that allows seamlessly component payment and contracting processes, reducing existing Product Order systems (*Consulting 1 – Appendix I; MRO 1 – Appendix X; MRO 2 – Appendix XIII; OEM – Appendix XV*). As a result, MROs acquire flexibility in their component sourcing strategies as they face the opportunity to acquire possibly cheaper components from locations that were not considered before and start relying upon a larger network of providers (*Consulting 1 – Appendix I, III; Consulting 2 – Appendix V*). The availability of component data through Blockchain could help MROs judge the quality of the components and analytically decide whether they want to source it (*Consulting 2 – Appendix VII, VIII; OEM – Appendix XV*). It shows potential in the acquisition repair process, as MROs gain the capability to proactively identify where a component must be sent to (*Consulting 1 – Appendix II*). This can potentially reduce the Aircraft-on-Ground downtime, where the Blockchain allow parties to coordinate ad-hoc when component data is digitally available in a 24-hour real-time basis (*MRO 2 – Appendix XIV*). In the end, it is still expected to do a visual check to evaluate whether the component condition reflects the data on the Blockchain (*MRO 2 – Appendix XIII*).

B5 – Quality Assurance

It is believed that Blockchain could improve component quality assurance processes, where each component is checked before it is installed on an aircraft (*Consulting 2 – Appendix V; MRO 1 – Appendix XI*). When all certificates and component data is accessible through the Blockchain, it could reduce the paperwork where QA must currently go through physical documents in order to determine whether the unit meets the aircraft configuration and regulatory criteria (*MRO 1 – Appendix XI*). This is relevant when the MROs deal with manually-tracked high-valued serial numbered limited life parts, which can be a problem since it is important to always understand what happens with these components (*MRO 1 – Appendix XI*). Therefore, it is possible to skip a majority of inspection of inbound components, since the Blockchain can clarify the status and location of a component with a notification (*MRO 2 – Appendix XIII, XIV*). It is no longer necessary to analyse and check the validity of the data and only do a visual check to verify the inclusion of the component (e.g. wheel) (*MRO 2 – Appendix XIII, XIV*).

B6 – Maintenance Troubleshooting

Increased component data through the Blockchain could improve maintenance troubleshooting processes, since sometimes it is necessary to disassemble an aircraft and engage in analysis with no knowledge (*Consulting 1 – Appendix II; MRO 2 – Appendix XIV*). To highlight one example: sometimes components are removed from the aircraft from an aircraft and afterwards the MRO receives a *No Failure Found* message from the removed part (*MRO 1 – Appendix XI; MRO 2 – Appendix XIII*). Another example is when an MRO receives an alternative component and determines in the end that the wrong component is installed (*MRO 2 – Appendix XIV*). With Blockchain-based component data, it is possible to assure that this unnecessary component replacement does not have to occur (*MRO 1 – Appendix XI; MRO 2 – Appendix XIII*).

B7 – Maintenance Execution

There is doubt that Blockchain could impact the core of labour-intensive maintenance activities, since it would not impact the manhours or the engineering nature of the task (*Consulting 2 – Appendix VI, VIII; MRO 1 – Appendix IX, X; MRO 2 – Appendix XIV; OEM – Appendix XV*). What will change is how changes in these processes are recorded, which could impact maintenance KPIs (e.g. repair reliability) (*Consulting 2 – Appendix VI, VIII*). However, when real-time data is available and clients have insight on the component cycle, MROs may be forced to only engage with maintenance when components reach their maximum lifecycle (*Consulting 2 – Appendix VIII*). On the other hand, when MROs gather structural client component intelligence, they could save a lot of labour when they must eventually engage in their client's maintenance program (*Consulting 1 – Appendix II*). Blockchain could help them further customise these programs, since component data is perceived more integer and regulatory authorities can access this data (*OEM – Appendix XV*). By providing more insight on the component through the Blockchain, MROs may not be necessarily forced to engage with the highest category of maintenance (complete overhaul) (*MRO 2 – Appendix XIV*).

5.1.3 Strategic impact of Blockchain on key resources

Key message: There is consensus among both consulting and industry participants that Blockchain as an aircraft spare part track and trace capability could have neutral impact on MRO key resources (**Table 13**).

Table 13 – Key Resources: respondent evaluation

	Consulting 1	Consulting 2	MRO 1	MRO 2	OEM	Total
5: Excellent	1 (6%)	0	0	0	0	**1 (6%)**
4: Good	0	1 (6%)	1 (6%)	2 (13%)	0	**4 (25%)**
3: Neutral	2 (13%)	2 (13%)	3 (19%)	0	2 (13%)	**9 (56%)**
2: Poor	1 (6%)	1 (6%)	0	0	0	**2 (13%)**
1: Very poor	0	0	0	0	0	**0**
Total	**4**	**4**	**4**	**2**	**2**	**16**

Key theme identification: To understand why respondents are neutral about the impact of Blockchain on the MRO key activities, the discussion is broken down into four key themes considered important by them (**Table 14**): 1) physical resources (**C1**); 2) intellectual resources (**C2**); 3) human resources (**C3**); 4) financial resources (**C4**).

Table 14 – Key Resources: frequency of each addressed theme

	Consulting 1	Consulting 2	MRO 1	MRO 2	OEM	Total
C1: Physical	27 (15%)	12 (7%)	15 (8%)	12 (7%)	13 (7%)	**79 (45%)**
C2: Intellectual	17 (10%)	4 (2%)	7 (4%)	10 (6%)	5 (3%)	**43 (24%)**
C3: Human	14 (8%)	11 (6%)	6 (3%)	5 (3%)	8 (5%)	**44 (25%)**
C4: Financial	3 (2%)	3 (2%)	1 (1%)	0	4 (2%)	**11 (6%)**
Total	**61 (34%)**	**30 (17%)**	**29 (16%)**	**27 (15%)**	**30 (17%)**	**177**

Summary: Blockchain is seen as a technology that acts as a trust mechanism alongside the digital canvas of RFID/IoT that provide component data and AI that provides the prognostic capabilities. However, Blockchain must be adopted as a complementary resource through which MROs can check whether components are within operational limits. Even though Blockchain should not replace existing MRO IT systems, it is considered a huge challenge to integrate Blockchain within this framework. This is why MROs must invest in the necessary IT and MRO business experts that can explain and prove the value of Blockchain. Despite its proposition, the immutability of Blockchain makes it difficult for MROs to correct mistakes or remove invalid component data, which justifies the position of regulators to require MROs to engage with physical paperwork regardless of Blockchain. Once Blockchain is adopted, it can help MROs extend their component analytics to ecosystem level, which gives them the commoditised ability to improve control over their aircraft configuration. This is possible since MROs acquire improved understanding of which part serial number is located in which section of the aircraft and whether the part is counterfeit. MROs could reduce their administrative capabilities related to processing trivial component data into maintenance systems. However, change management can be perceived problematic when back office employees feel threatened and protest. Therefore, MROs might not want to participate in Blockchain if they face the problems of managing large inventories, the immutability of Blockchain and the resistance towards change management. However, when more parties do not participate in the Blockchain, component data and tracking capabilities diminish. This shows that Blockchain is a technology that requires consideration of changes in regulation, business processes, culture and mindset. Large innovative MROs might have the finance to engage with Blockchain, but they face infrastructural sunk costs that might make it difficult to see past those commitments. Smaller MROs without these intermediate commitments might be in a better position to incorporate the necessary changes. However, it is difficult to develop a business case that puts these smaller MROs in a position to allocate manpower and capital to Blockchain projects.

C1 – Physical resources

Blockchain and existing MRO IT systems

There is consensus that Blockchain would not replace any existing MRO IT systems (e.g. ERP) and that it is necessary to connect Blockchain with those systems (*Consulting 1 – Appendix I, II, IV; MRO 1 – Appendix IX, X, XI; MRO 2 – Appendix XIII; OEM – Appendix XV*). As MROs use different IT systems and databases to process component data, it is difficult for participants to see how Blockchain can be integrated with these systems to exchange data (*Consulting 1 – Appendix I, II, IV*). These IT systems are connected and integrated through the entirety of component logistic processes that are subject to a huge quantity of components that regularly enter the supply chain and maintenance (*Consulting 1 – Appendix I, II*). However, since SAP allowed component data standardisation and digitalisation on MRO enterprise level, Blockchain could have this same impact on an aviation industry level (*Consulting 1 – Appendix IV; MRO 2 – Appendix XIV*). If Blockchain were to be used as an aircraft spare part track and trace capability, all supply chain participants must be able to sync their ERP systems with the Blockchain (*Consulting 1 – Appendix I, IV*). Therefore, until Blockchain can be fully integrated with existing IT systems, Blockchain would act as a shared logbook that contains information on spare parts than as a decision-making tool for supply chain participants (*Consulting 1 – Appendix I*). However, Blockchain can remedy the limitation of current IT, since it is difficult to process and register individual parameters of a component that are recorded by the aircraft (*MRO 2 – Appendix XIII*). For that reason, Blockchain might replace the Continuous Airworthiness Management Program, since there is increased insight on cycles and overhaul on component level (*MRO 2 – Appendix XIII*). The challenge in integrating Blockchain as a complementary resource necessitates such endeavours to smart small before extending it (*Consulting 1 – Appendix II*).

Blockchain and RFID/IoT devices

There is consensus that once the technology is better understood, Blockchain could be seen as part of the digital technology canvas, alongside RFID, IoT, additive manufacturing and AI (*MRO 1 – Appendix IX; OEM – Appendix XV, XVI*). Aircraft spare parts are typically equipped with RFID tags and IoT devices to send traceability and reliability data to ground stations, which allow MROs and operators to identify and localise the asset (*Consulting 1 – Appendix II, IV*). The interaction between Blockchain, RFID and IoT is important: if invalid data ends up on the Blockchain, it is impossible to remove it (*MRO 1 – Appendix X*). Therefore, in this technological interaction, Blockchain would act as a trust record mechanism that verifies and validates component data, which would make it difficult for an RFID or IoT device to populate the Blockchain with invalid inaccurate component data (*OEM – Appendix III*). If Blockchain would require MROs to invest in these or new IT capabilities to reach the required level of IT sophistication, it might impose a higher barrier of adoption for the MRO industry (*Consulting 2 – Appendix VI*). On the other hand, if Blockchain is nothing more than a web-based platform in which participants can feed in their data, it may be more widely accepted by MROs with fewer capabilities (*MRO 1 – Appendix XI*). Even so, MROs have recently invested in portals and API infrastructures to share data more seamlessly (*Consulting 2 – Appendix VII, VIII*). The data that would end up in the Blockchain is already available (e.g. component history and location), but it is currently confined to individual MRO IT systems in traditional maintenance operations and is typically not traced back to birth (*Consulting 2 – Appendix VII; MRO 2 – Appendix XIII*).

Blockchain, smart contracts and AI

If the business logic is strict and well documented, it is possible to code anything (e.g. airworthiness certificate generation) on the smart contract (*Consulting 1 – Appendix III*). These contracts can be used to check whether the component data is correct and within limits to allow certificate generation (*Consulting 1 – Appendix III*). This can go one step further by adopting artificial intelligence that work with Blockchain data and smart contracts to automate the regulatory process (*Consulting 1 – Appendix III, MRO 1 – Appendix IX; OEM – Appendix XV*).

However, the immutability of Blockchain and smart contracts might make it difficult or impossible to correct mistakes (*MRO 1 – Appendix IX, X*). This could also be a problem if new Airworthiness Directives or Service Bulletins were published that changes maintenance standards (*MRO 2 – Appendix XIII*). This introduces rigidity into the system, since all parties are expected to immediately enforce these directives (*MRO 2 – Appendix XIV*). Therefore, if smart contracts were going to be used for the purpose of certificate generation, this process must be jointly set up with the authorities (*MRO 1 – Appendix X*). In the end: RFID and IoT provides the component data; Blockchain provides the trust; AI provides the prognostics (*OEM – Appendix XV*).

Blockchain and physical paperwork

Any entity operating with aircraft spare parts is always required to work with physical paperwork and maintain a digital copy, as required by regulatory authorities (*Consulting 2 – Appendix V, VI, VII*). If MROs store data on the Blockchain, they should be able to print out the relevant paperwork and present it to the authority (*Consulting 2 – Appendix VI*). In this scenario, the authorities are not interested in how the data is stored, as long as they believe that the MRO has rigorous spare part tracking mechanisms (*Consulting 2 – Appendix VI*). However, even though it is difficult to tamper with Blockchain data, it is possible for other failures (e.g. RFID/IoT security gap) to occur, which the regulators will care about (*Consulting 2 – Appendix VI*). Even though these regulatory considerations complicate the industry and supply chain dynamics, it does not necessarily mean that Blockchain could not be successful (*OEM – Appendix XVI*). However, once there is regulatory support, components might no longer be certified with stamps on paper documents, but with the immutable Blockchain data (*MRO 2 –Appendix XIII*). In the end a transition might happen from components with paper logbooks and cards that can lose easily or have unclear information to components as a digital information carrier that provides full maintenance and fault history (*MRO 2 – Appendix XIV*).

C2 – Intellectual resources

Aircraft configuration

With the huge number of components entering the market, MROs do not always understand which part and serial number is located in which section of the aircraft (*Consulting 1 – Appendix I, II; MRO 1 – Appendix XI; MRO 2 – Appendix XIII; OEM – Appendix XV*). This is especially true for Chinese aircraft spare parts, which uses a different part numbering system than in Europe (*Consulting 1 – Appendix II; MRO 1 – Appendix XI*). With component transparency offered by Blockchain, MROs are more in control over the aircraft configuration (*Consulting 1 – Appendix II, IV*). Four primary factors contribute to this increased control: 1) MROs would understand what happens when customers engage in component base maintenance (*Consulting 1 – Appendix II*); 2) MROs can ensure clients that they do not operate with counterfeit components that are introduced by brokers (*Consulting 1 – Appendix III; MRO 2 – Appendix XIII, XIV; OEM – Appendix XV*); 3) Blockchain would provide an overview of all data of all components that are acquired by MROs (*MRO 1 – Appendix XI; MRO 2 – Appendix XIII*); 4) MROs will have increased insight in alternative components, since the Blockchain would show that they receive a different compatible component over the one they ordered (*MRO 2 – Appendix XIV*).

Data quality

The quality of the Blockchain depends on whether the information is entered consistently, which might be difficult for an MRO that faces a huge quantity of components (*Consulting 1 – Appendix I*). It is important that this data is correct: when the data is kept by the MRO, they attain control, ownership and responsibility for any mistake (*Consulting 1 – Appendix II*). If this data is shared through the Blockchain, it raises the question which party is responsible for maintaining data quality and integrity (*Consulting 1 – Appendix II*). Furthermore, it is not considered desirable if the Blockchain is only set up between a few parties, since it is possible to lose tracking capabilities and component data when industry participants do not engage with the Blockchain consortium (*MRO 1 – Appendix X; MRO 2 – Appendix XIII*). What Blockchain can help with is threading together information from MRO IT (e.g. CRM, ERP – in-office tools and systems) and OT (operating technologies that support the maintenance environment), which can support the maintenance decision and execution layer (*OEM – Appendix XVI*).

Ecosystem-based analysis

Blockchain would enable a holistic view of all spare parts of all parties, which help MROs extend their analytical perspective to ecosystem level and optimise based on the integral stock (*Consulting 1 – Appendix II, III; Consulting 2 – Appendix VII; MRO 2 – Appendix XIII*). This intelligence can be used to provide advice based on Blockchain data, which is a capability that is not possessed by those who do not participate in the consortium (*Consulting 1 – Appendix II; Consulting 2 – Appendix V; MRO 1 – Appendix X, XI*). However, the main problem is that once the Blockchain is widely deployed and all participants analyse the same component data, the ecosystem-based analysis becomes commoditised (*Consulting 2 – Appendix VII; MRO 1 – Appendix XI*). Therefore, there is doubt whether MROs would share the reliability data through a Blockchain platform (*Consulting 2 – Appendix VIII; MRO 1 – Appendix X, XI*). Even though MROs will not be fully transparent with data, in order for the ecosystem to have value it is necessary to forge certain degree of cooperation and information sharing among Blockchain participants (*OEM – Appendix XV*). As a result, varying degrees of cooperative and non-cooperative analysis of spare parts will emerge (*OEM – Appendix XV*). Non-cooperative analysis is when an ecosystem participant (e.g. operator) engages in analysis that is not relevant for the overall ecosystem (e.g. weather conditions) (*OEM – Appendix XV*).

C3 – Human resources

Currently, employees must manually process a lot of (trivial) component data into maintenance system, which is subject to human error (*Consulting 1 – Appendix I, II; Consulting 2 – Appendix VII*). When Blockchain can be implemented, it can help the team that is responsible for developing reliability reports and addressing inquiries by reducing manual labour and human error (*Consulting 2 – Appendix VII*). On the other hand, if Blockchain and smart contracts are used to automate these administrative processes (e.g. billing, certificate generation), it is possible that back-office employees might lose their job (*MRO 1 – Appendix X; MRO 2 – Appendix XIV*). The scope and activities of CAMO, for example, might reduce to a five-minute check of the aircraft (*MRO 2 – Appendix XIV*). This could also apply to auditing, since the Blockchain would record when the component is installed on an aircraft (*MRO 2 – Appendix XIV*). Their activities might reduce to auditing from the computer and sometimes attend an A-Check to verify whether the component is actually installed on an aircraft (*MRO 2 – Appendix XIV*). However, a problem in this change management is that MROs might face resistance from experienced engineers who:

1. Do not want IT to tell them how an aircraft must be maintained (*Consulting 1 – Appendix I; Consulting 2 – Appendix V*);
2. Are sceptical and rely on the argument to use known and safe technologies (*OEM – Appendix XV*);
3. Are conservative due to the regulatory, risk-averse nature of the MRO industry (*Consulting 1 – Appendix IV; OEM – Appendix XV*);
4. Consider safety as the most important factor in decision-making (*Consulting 2 – Appendix VIII*);
5. Would be displaced from their current skills and have to learn new ones (*OEM – Appendix XV*);
6. Are content with current information exchange standards and practices (*MRO 1 – Appendix IX*);
7. Might not accept the prospect that a separate Blockchain web/mobile application would be used for each type or brand of aircraft (*MRO 1 – Appendix IX*).

The human resistance to technology is a classic model and even though this resistance is rational, its persistence is considered irrational (*OEM – Appendix XV*). Eventually, if something dramatic would happen, people might eventually be forced to study and understand how Blockchain can be leveraged (*OEM – Appendix XVI*). Human resistance is one factor that negatively affected RFID's success and could happen to Blockchain (*Consulting 1 – Appendix I*). Therefore, to convince these employees and initiate a cultural change, the functionalities of Blockchain must be well proven and explained (*MRO 1 – Appendix IX; OEM – Appendix VIII*). This also requires change management for established MRO business processes (*Consulting 1 – Appendix III*). This means that if Blockchain is implemented without considering any changes in regulation, business processes and culture, the endeavour might fail (*OEM – Appendix VIII*).

The innovation departments of the MROs are educating and preparing themselves for Blockchain (*Consulting 1 – Appendix III; MRO 1 – Appendix XI*). It is necessary for MROs to develop the necessary capabilities that allow them to establish and maintain the Blockchain (*Consulting 1 – Appendix II*), which requires the presence of Blockchain IT and MRO business experts (*MRO 1 – Appendix X*). However, since it is an engineering environment, MROs typically have the right human resources to develop these capabilities (*Consulting 1 – Appendix III; Consulting 2 – Appendix V; MRO 2 – Appendix XIV*).

C4 – Financial resources

There is scarcity of capital, which means that an IT organisation often does not have the necessary capacity to approach IT projects within an acceptable turnaround time (*Consulting 1 – Appendix I*). Even though MROs could technically implement Blockchain if the desire is there, it is necessary to develop a business case that puts them in a position to allocate manpower and capital to these endeavours (*Consulting 1 – Appendix I; MRO 1 – Appendix XI*). Only large MROs might have the right financial capabilities to engage with Blockchain projects, since a lot of MROs are primarily focused on reducing labour costs (*Consulting 2 – Appendix VI*). Those who adopt cost-cutting strategies typically have not invested in complicated system capabilities, which could make it even more difficult for these MROs to allocate finances to Blockchain related projects (*Consulting 2 – Appendix VI, VII*). Even regulators, such as EASA and FAA might not want to push Blockchain, since they face a lot of fiscal austerity and budget problems (*Consulting 2 – Appendix VI*). On the other hand, large incumbent MROs with the right resources may not necessarily be in the ideal position to invest in Blockchain (*OEM – Appendix XVI*). The problem is that due to infrastructural sunk costs, these MROs might have a difficult time seeing past those commitments and approach problems through that lens (*OEM – Appendix XVI*). Smaller MROs who may not have made these intermediate commitments (e.g. infrastructure, roadmap and partnerships) might be in a better position to adopt Blockchain (*OEM – Appendix XVI*).

5.1.4 Strategic impact of Blockchain on value proposition

Key message: Both consulting and industry participants are divided about how Blockchain as an aircraft spare part track and trace capability could impact the MRO value proposition (**Table 15**).

Table 15 – Value Proposition: respondent evaluation

	Consulting 1	Consulting 2	MRO 1	MRO 2	OEM	Total
5: Excellent	1 (6%)	0	0	1 (6%)	1 (6%)	3 (19%)
4: Good	0	2 (13%)	3 (19%)	0	0	5 (31%)
3: Neutral	3 (19%)	1 (6%)	1 (6%)	1 (6%)	1 (6%)	7 (44%)
2: Poor	0	1 (6%)	0	0	0	1 (6%)
1: Very poor	0	0	0	0	0	0
Total	4	4	4	2	2	16

Key theme identification: To understand why respondents are divided about the impact of Blockchain on the MRO value proposition, the discussion is broken down in three key themes considered important by them (**Table 16**): 1) MRO core value proposition (**D1**); 2) ecosystem-based analysis (**D2**); Blockchain as a Service (**D3**).

Table 16 – Value Proposition: frequency of each addressed theme

	Consulting 1	Consulting 2	MRO 1	MRO 2	OEM	Total
D1: Core value	1 (3%)	4 (13%)	3 (10%)	1 (3%)	2 (6%)	11 (35%)
D2: Analysis	3 (10%)	4 (13%)	2 (6%)	2 (6%)	0	11 (35%)
D3: BaaS	3 (10%)	3 (10%)	1 (3%)	2 (6%)	0	9 (30%)
Total	7 (23%)	11 (35%)	6 (19%)	5 (16%)	2 (6%)	31

Summary: Blockchain can help MROs differentiate themselves by offering the same maintenance services to operators at reduced prices. This is possible since they can take advantage of transparent component data to take calculated risk on performance and inventory levels, which can help them improve Power by Hour business arrangements. However, the core MRO value proposition of providing maximised aircraft availability to operators will not be affected by Blockchain. What can be affected by Blockchain is the ability of MROs to provide new Blockchain-based consultancy services to 1) authorities that require guidance in the new Blockchain ecosystems and 2) aircraft operators that require detailed insight in component status. The problem is that this proposition can easily be commoditised once all participants access the same component data, which makes it difficult for MROs to fully differentiate themselves with Blockchain properties. Alternatively, innovative MROs can decide to offer Blockchain as a Service to other aviation industry participants who might not have the necessary resources to consider Blockchain as anything more than a web portal. Through this service, MROs could potentially acquire subscription revenues from external parties that wish to join the network. However, there are a few problems with this value proposition: 1) this proposition is only valid if the owner is capable to convince other cost-conscious parties to participate; 2) this proposition conflicts the core principle of Blockchain that is supposed to remove opportunistic owners and intermediaries; 3) this proposition is threatened by the Blockchain industry, where specialised architect agencies can develop Blockchain services for prospective clients.

D1 – MRO core value proposition

The core value proposition of an MRO is to ensure that repairs are done in a short turnaround time in order to allow the aircraft operator to maximise its aircraft availability, which might not be affected by Blockchain (*Consulting 1 – Appendix IV; Consulting 2 – Appendix VI, VII; MRO 1 – Appendix IX*). However, the presence of transparent component data should help MROs take calculated risk on performance and inventory levels, which could help them improve their Power by Hour business arrangements (*Consulting 2 – Appendix VII; MRO 1 – Appendix IX; OEM – Appendix XVI*). As a result, MROs might be able to reduce the internal costs through improved business and maintenance performance, through which they can differentiate themselves by offering the same services to their client at reduced price (*Consulting 1 – Appendix IV; Consulting 2 – Appendix VIII; MRO 1 – Appendix X; MRO 2 – Appendix XIII; OEM – Appendix XVI*).

D2 – Ecosystem-based analysis

Ecosystem-based analysis refers to the intellectual resource of MROs to adopt a holistic view and extend their component analysis from organisation to ecosystem level (*Consulting 1 – Appendix II, III; Consulting 2 – Appendix VII; MRO 2 – Appendix XIII*). With ecosystem-based analysis as an intellectual resource, it is possible to develop value propositions on the prospect of shared Blockchain spare part data (*Consulting 1 – Appendix III; MRO 2 – Appendix XIII*). One example is where the MRO with better data analytics could provide analytic-based Blockchain consulting services to authorities that require guidance in these ecosystems (*Consulting 1 – Appendix III; Consulting 2 – Appendix VII*). A second example is where MROs might try to sell predictive maintenance services using Blockchain data, where the client provides component data in order to receive spare part reliability recommendations (e.g. when and which parts must be changed) (*Consulting 1 – Appendix III; Consulting 2 – Appendix VII; MRO 1 – Appendix X*). The problem of monetising these data feeds is that OEMs are already part of this competition, which might raise the question to what extent OEMs will open up the component data on the Blockchain (*Consulting 2 – Appendix VII*). A second problem is that MROs do not want to share data that exposes their predictive maintenance, since they differentiate themselves on the market with this service (*MRO 2 – Appendix XIII*). Therefore, this proposition can only work if the intellectual resource is not commoditised (*Consulting 2 – Appendix VII; MRO 1 – Appendix XI; MRO 2 – Appendix XIII*).

D3 – Blockchain as a Service

The owner of the Blockchain platform can provide Blockchain as a service to other MROs and allocate a subscription fee for external partners that wish to join the network (*Consulting 1 – Appendix IV; Consulting 2 – Appendix VI, VII; MRO 1 – Appendix XI; MRO 2 – Appendix XIII*). For this proposition to work, it is necessary to realise network effect by convincing other industry members to participate (*Consulting 1 – Appendix I*). One way to realise this is by ensuring that the Blockchain is built in a way that allows others to enter without investing in any complex IT systems (*MRO 1 – Appendix XI*). If MROs voluntarily engage with Blockchain in the short-term, it will be difficult to convince other cost-conscious MROs to raise their costs (*Consulting 2 – Appendix VI*). If the initiating MRO is not able to realise this network effect, then they may as well use their own standard applications over Blockchain (*Consulting 1 – Appendix IV; Consulting 2 – Appendix VI*). Furthermore, it can be questioned whether this service will be of value to the MRO, since the Blockchain industry is an industry on its own where specialised architect agencies can develop the Blockchain for prospective clients (*MRO 2 – Appendix XIV*).

5.1.5 Strategic impact of Blockchain on cost structure

Key message: There is consensus among both consulting and industry participants that Blockchain as an aircraft spare part track and trace capability could positively impact MRO cost structure (**Table 17**)

Table 17 – Cost Structure: respondent evaluation

	Consulting 1	Consulting 2	MRO 1	MRO 2	OEM	Total
5: Excellent	0	0	0	1 (6%)	0	**1 (6%)**
4: Good	2 (13%)	3 (19%)	2 (13%)	1 (6%)	1 (6%)	**9 (56%)**
3: Neutral	2 (13%)	0	1 (6%)	0	1 (6%)	**4 (25%)**
2: Poor	0	1 (6%)	1 (6%)	0	0	**2 (13%)**
1: Very poor	0	0	0	0	0	**0**
Total	**4**	**4**	**4**	**2**	**2**	**16**

Key theme identification: To understand why respondents are positive about the impact of Blockchain on the MRO cost structure, the discussion is broken down in five key themes considered important by them (**Table 18**): 1) inventory costs (**E1**); 2) part purchase costs (**E2**); 3) IT costs (**E3**); 4) administrative, communication and logistics costs (**E4**); maintenance costs (**E5**).

Table 18 – Cost Structure: frequency of each addressed theme

	Consulting 1	Consulting 2	MRO 1	MRO 2	OEM	Total
E1: Inventory	2 (4%)	5 (9%)	3 (5%)	0	2 (4%)	**12 (22%)**
E2: Purchase	5 (9%)	1 (2%)	0	0	1 (2%)	**7 (13%)**
E3: IT	5 (9%)	4 (7%)	3 (5%)	2 (4%)	0	**14 (25%)**
E4: Admin	7 (13%)	6 (11%)	3 (5%)	0	0	**16 (29%)**
E5: Maintain	2 (4%)	3 (5%)	1 (2%)	0	0	**6 (11%)**
Total	**21 (38%)**	**19 (35%)**	**10 (18%)**	**2 (4%)**	**3 (5%)**	**55**

Summary: Blockchain can help MROs marginally reduce inventory costs through improved inventory management on the prospect that 1) parties share sensitive component data and; 2) MROs can develop new predictive maintenance models. However, since Blockchain can offer flexible component sourcing strategies, MROs can potentially reduce part purchase costs by purchasing cheaper components from locations that were not considered before. Furthermore, Blockchain can reduce administrative costs through reduced back-office labour activities; communication costs are reduced through reduced interactions; logistic costs are reduced through reliable tracking practices. Blockchain can only reduce maintenance costs if small MROs face additional checks or overhaul because they operate with limited component data and historical records. Unfortunately, it is difficult to quantify these cost reductions for two reasons: 1) a Blockchain cost model is not developed or is unknown; 2) to properly evaluate these reductions, it is necessary to first implement Blockchain. These reasons also complicate the evaluation of the one-time short-term cost of IT transition and ongoing long-term cost to support and maintain the Blockchain.

E1 – Inventory costs

One of the major MRO costs are inventory costs, since a lot of capital is involved to move spare parts around the world (*Consulting 1 – Appendix I*). On the prospect that Blockchain can result in improved inventory management, it is possible for an MRO to reduce its inventory costs (*Consulting 1 – Appendix II; Consulting 2 – Appendix VII, VIII; MRO 1 – Appendix IX; OEM – Appendix XV*). Even though the MRO might experience less inventory risks and reduced part depreciation costs, Blockchain could only have marginal impact on these savings (*Consulting 1 – Appendix VII*). However, to make any concrete statements how much an MRO could reduce its inventory costs, it is necessary to involve component stock statistics in order to properly evaluate the cost differences (*MRO 1 – Appendix IX*).

E2 – Part purchase costs

Due to flexible component sourcing strategies, it is possible to reduce part purchase costs by purchasing cheaper components from locations that were not considered before (*Consulting 1 – Appendix I, II, III; Consulting 2 – Appendix V*). There might be unique situations where these costs might increase, for example when an MRO that relies on cheap used spare parts would switch to components with proper records (*Consulting 1 – Appendix III; Consulting 2 – Appendix VII*). Finally, an unknown cost impact could result from disintermediation in the component supply chain, where MROs would purchase its components directly from OEMs (*OEM – Appendix XV*).

E3 – IT costs

Participants have diverse perspectives on whether the overall MRO IT costs would increase (*Consulting 1 – Appendix II; Consulting 2 – Appendix VI; MRO 1 – Appendix IX, X, XI; MRO 2 – Appendix XIV*), stay the same (*Consulting 1 – Appendix III*), or decrease (*Consulting 1 – Appendix IV*). One major reason is due to the fact that interviewees do not know the costs of Blockchain IT participation (*Consulting 1 – Appendix III; Consulting 2 – Appendix VI, VII, VIII; MRO 1 – Appendix IX, X; MRO 2 – Appendix XIII*). The arguments can be summarised:

- Argument for increase in IT costs: There is a one-time short-term cost of IT transition and an ongoing long-term cost to support and maintain the Blockchain (*Consulting 2 – Appendix VI*).
- Argument for no change in IT costs: Blockchain IT solution is light (*Consulting 1 – Appendix III*).
- Argument for reduction in IT costs: The usage of Blockchain could potentially reduce the complexity of existing IT systems (*Consulting 1 – Appendix IV*).

E4 – Administrative, communication and logistics costs

The premise of the Blockchain to process and communicate component data entries automatically could save up administrative labour (*Consulting 1 – Appendix I*), since currently this data must be requested manually through maintenance planning software (*Consulting 1 – Appendix II*). The presence of back-to-birth component records could help MROs automate manual labour (e.g. component data entries, QA, contracting), reduce overall administrative costs, reduce logistics costs as components are tracked with reliability and predictivity and reduce the costs associated with communication between MROs and their partners (*Consulting 1 – Appendix I, II, III, IV; Consulting 2 – Appendix V, VII; MRO 1 – Appendix IX, X*).

E5 – Maintenance costs

The costs associated with labour-intensive maintenance will most likely not reduce (*Consulting 1 – Appendix II, III; Consulting 2 – Appendix V, VIII; MRO 1 – Appendix XI*). A unique condition in which the maintenance costs could reduce is when a small MRO or operator extensively exchanges components or aircraft and does not have a dedicated fleet management team (*Consulting 2 – Appendix VI*). These entities face additional maintenance checks and overhauls, because the component data and records are limited (*Consulting 2 – Appendix VI*).

5.1.6 Strategic impact of Blockchain on revenue structure

Key message: Both consulting and industry participants are divided about how Blockchain as an aircraft spare part track and trace capability could impact the MRO revenue structure (**Table 19**).

Table 19 – Revenue Structure: respondent evaluation

	Consulting 1	Consulting 2	MRO 1	MRO 2	OEM	Total
5: Excellent	0	0	0	0	0	**0**
4: Good	2 (13%)	1 (6%)	2 (13%)	1 (6%)	1 (6%)	**7 (44%)**
3: Neutral	1 (6%)	1 (6%)	1 (6%)	1 (6%)	1 (6%)	**5 (31%)**
2: Poor	1 (6%)	2 (13%)	1 (6%)	0	0	**4 (25%)**
1: Very poor	0	0	0	0	0	**0**
Total	**4**	**4**	**4**	**2**	**2**	**16**

Key theme identification: To understand why respondents are divided about the impact of Blockchain on the MRO revenue structure, the discussion is broken down into two key themes considered important by them (**Table 20**): 1) negotiation position (**F1**); 2) competitive position (**F2**).

Table 20 – Revenue Structure: frequency of each addressed theme

	Consulting 1	Consulting 2	MRO 1	MRO 2	OEM	Total
F1: Negotiation	5 (9%)	8 (15%)	2 (4%)	2 (4%)	0	**17 (31%)**
F2: Compete	6 (11%)	9 (17%)	3 (6%)	17 (31%)	2 (4%)	**37 (69%)**
Total	**11 (20%)**	**17 (31%)**	**5 (9%)**	**19 (35%)**	**2 (4%)**	**54**

Summary: The ability of Blockchain to provide historical records to all network participants affects the negotiation dynamics between MROs, OEMs and operators. MROs would lose their negotiation position when they face real price transparency, component cycle transparency or when they take advantage of operator data that is shared through the Blockchain. They maintain their negotiation position against operators when they face an emergency situation (e.g. Aircraft-on-Ground) where time is more crucial than capital. Through the availability of component historical records, MROs can increase their negotiation position against component suppliers and manufacturers. On the other hand, the ability of Blockchain to provide historical records to all network participants also affect the competitive dynamics of the MRO industry. When MROs accept reduced information asymmetry and face the potential prospect of commoditising analytical capabilities, they could lose their competitive position as the MRO industry would become more competitive. However, depending on how the Blockchain is deployed and how this translated to ecosystem transparency, it is unknown which parties will gain and lose. MROs would not necessarily lose their competitive position if Blockchain is commoditised as an industry standard and still rely on the efficiency of their maintenance services to differentiate themselves. Moreover, Blockchain can be considered disruptive for three reasons: 1) smaller MROs can take advantage of component data of larger MROs; 2) component broker intermediaries can be removed from the supply chain; 3) when a certain party (e.g. OEM) owns the Blockchain, they could drive out competitors that are purposefully excluded from the network.

F1 – Negotiation position

A major problem imposed with Blockchain is that once all participants possess the same component data (e.g. location, value), MROs might lose their negotiation position against their clients (aircraft operators) for three reasons (*Consulting 1 – Appendix I*):

1. Real price transparency: Due to the high demand for aircraft and component maintenance, MROs typically allocate a premium price to their products and services (*Consulting 1 – Appendix I, II, IV; Consulting 2 – Appendix V*). When the Blockchain provides historical records on the spare parts, clients would decline the overvalued services in favour of a competitor that provides it at reduced market price (*Consulting 1 – Appendix I, II*). As a result of reduced negotiation position that follows increased component transparency, it is difficult for MROs to charge premium prices (*Consulting 1 – Appendix II, IV; Consulting 2 – Appendix V, VII*).
2. Component cycle transparency: Currently MROs maintain components a certain percentage of the component cycle before it should actually be maintained, which is one source of MRO profits (*Consulting 2 – Appendix VIII*). However, with real-time component data availability, clients would expect MROs to maximise these cycles and engage in less frequent maintenance (*Consulting 2 – Appendix VIII*).
3. Using data from operators: Another circumstance where MROs would lose its negotiation position is when they use Blockchain data from operators to provide predictive maintenance services (*Consulting 2 – Appendix VII*). This circumstance is only a threat when analytical operators want to tightly manage the maintenance contract with its MRO provider and demand reduced rate from MROs for using their data (*Consulting 2 – Appendix VII*).

There is one circumstance in which the MRO might maintain their negotiation position against their clients:

1. Emergency situations: MROs will maintain their negotiation position in circumstances when an aircraft operator is in an emergency (e.g. Aircraft-on-Ground) with passengers waiting for take-off (*Consulting 1 – Appendix II, IV*). In these emergency circumstances where time is an important factor, the operator would still be willing to pay the premium price, regardless of whether Blockchain provides transparent component data (*Consulting 1 – Appendix II, IV*).

Furthermore, there are three circumstances in which the MRO might actually improve their negotiation position against operators and OEMs:

1. Component exchange: MROs can create a negotiation position against its component suppliers, since they have increased insight on history and reliability of the component over the past year (*MRO 2 – Appendix XIII*).
2. Component pool forecasting: It is possible to couple Blockchain with predictive maintenance to forecast component pool volume, which can help MROs acquire negotiation against their clients in a certain period (*MRO 2 – Appendix XIII*).
3. Component recommendations: A final consideration relates to the negotiation dynamics between the MRO and OEM, where OEMs provide part recommendations that is difficult to quantify and leverage around (*MRO 1 – Appendix X*). With the Blockchain, both MROs and operators should be able to leverage around the OEM using immutable component data (*MRO 1 – Appendix X*).

F2 – Competitive position

It is considered difficult for MROs to become accustomed with sharing data with other parties (*Consulting 1 – Appendix I, II; Consulting 2 – Appendix VII, VIII; MRO 1 – Appendix X; OEM – Appendix XVI*). The main reason is that competitors can use this data to engage in analytics and improve their own operations, which means that an MRO could sacrifice its competitive position (*Consulting 1 – Appendix II, III; Consulting 2 – Appendix V*).

This is also true for the competitors that currently rely upon components with incomplete historical records, showing that Blockchain does not result in a win-win situation for all parties (*Consulting 1 – Appendix III; Consulting 2 – Appendix V*). However, the chance of MROs consciously looking for cheap counterfeit parts with high risk is low in an EASA regulated environment (*MRO 2 – Appendix XIII, XIV*). Depending on how the Blockchain is deployed and how this translates to ecosystem transparency, it is currently unknown which parties will gain and lose (*Consulting 1 – Appendix IV*).

If Blockchain is considered an industry standard in which all MROs are expected to participate, then in the end MROs will not necessarily face a loss of competitive position (*Consulting 2 – Appendix VI*). If the resource is commoditised, Blockchain cannot help MROs differentiate themselves to their client (*MRO 2 – Appendix XIV*). In that regard, the revenue structure might not change as much, since they still differentiate with the efficiency and speciality of their maintenance services (*MRO 2 – Appendix XIV*). If Blockchain is a capability that can only be adopted by larger MROs, they may have an advantage compared to smaller MROs (*Consulting 2 – Appendix VI*). At the same time, if those smaller MROs can access data of larger MROs through the Blockchain, the larger MROs might lose their competitive advantage (*MRO 1 – Appendix XI; OEM – Appendix XV*).

The possibility of smaller MROs to enter the MRO segment is considered the first disruptive nature of Blockchain (*Consulting 1 – Appendix III*). The second disruptive nature of Blockchain is its ability to remove (shady) component broker intermediaries, which are component distributors between the suppliers and clients (*MRO 2 – Appendix XIII, XIV*). This is the market that typically realises and distributes most counterfeit components (*MRO 2 – Appendix XIV*). The third disruptive nature of Blockchain emerges if a certain party (e.g. OEM) owns the Blockchain, which gives them the ability to drive out competitors out of the market when they do not participate with Blockchain (*MRO 2 – Appendix XIII, XIV*). It shows that Blockchain can be seen as an OEM tool and capability that help them drive out smaller MROs and service centres from the market (*MRO 2 – Appendix XIV*).

5.1.7 Strategic impact of Blockchain on customer relationships

Key message: Both consulting and industry participants are divided about how Blockchain as an aircraft spare part track and trace capability could impact the MRO customer relationships (**Table 21**).

Table 21 – Customer Relationships: respondent evaluation

	Consulting 1	Consulting 2	MRO 1	MRO 2	OEM	Total
5: Excellent	0	0	2 (13%)	0	0	**2 (13%)**
4: Good	1 (6%)	2 (13%)	1 (6%)	0	2 (13%)	**6 (37%)**
3: Neutral	3 (19%)	2 (13%)	1 (6%)	1 (6%)	0	**7 (44%)**
2: Poor	0	0	0	1 (6%)	0	**1 (6%)**
1: Very poor	0	0	0	0	0	**0**
Total	**4**	**4**	**4**	**2**	**2**	**16**

Key theme identification: To understand why respondents are divided about the impact of Blockchain on the MRO customer relationships, the discussion is broken down in one key theme considered important by them (**Table 22**): customer interactions (**G1**).

Table 22 – Customer Relationships: frequency of each addressed theme

	Consulting 1	Consulting 2	MRO 1	MRO 2	OEM	Total
G1: Interaction	7 (33%)	5 (24%)	6 (29%)	1 (4%)	2 (10%)	**21 (100%)**
Total	**7 (33%)**	**5 (24%)**	**6 (29%)**	**1 (4%)**	**2 (10%)**	**21**

Summary: Blockchain can provide increased data transparency and immutable records, which redirects the client discussion from part compatibility and information exchange to strategic contracting and Service Level Agreements. MROs would face less phone and mail-based component-related disputes and bargaining. However, it can be questioned whether Blockchain would actually affect the way that MROs maintain their customer relationships. Furthermore, it can be questioned whether changes in the nature of the discussion would truly have enormous impact on the MRO-operator relationships.

G1 – Customer interactions

Currently operators engage in interaction with MROs to dispute whether the spare part can be installed and whether the part matches the aircraft configuration (*Consulting 1 – Appendix I, II*). Since it is difficult to find the right component that matches the right aircraft configuration, participants engage in a lot of phone and mail communication in order to determine the historical origin of a spare part (*Consulting 1 – Appendix I*). With Blockchain, this interaction is limited to only one phone call in order to purchase the spare part (*Consulting 1 – Appendix I, III*). Essentially, this redirects the focus of discussion from part compatibility and information exchange to contracting and Service Level Agreements (*Consulting 1 – Appendix II; MRO 1 – Appendix IX, XI; MRO 2 – Appendix XIV*). As a result of increased data transparency and an immutable record provided by the Blockchain, parties would face fewer component-related disputes and bargaining (*Consulting 1 – Appendix II; MRO 1 – Appendix IX, X*).

Operators rely on component data (e.g. type of maintenance, time of maintenance, origin of failure) in order to take an informed decision regarding aircraft airworthiness (*Consulting 2 – Appendix V; OEM – Appendix XVI*). Therefore, it can be frustrating for clients when they cannot acquire the right information, especially since: 1) different channels are involved (*Consulting 2 – Appendix VII*), 2) very few MROs and operators are integrated from an IT perspective (*Consulting 2 – Appendix V, VII*) and 3) they typically receive a different component from a pool (*MRO 1 – Appendix XI*). Clients become enthusiastic if Blockchain is mentioned as a capability, even though few understand it (*MRO 1 – Appendix XI*). Eventually, operators might require MROs to invest in the Blockchain capability, since it benefits them (*Consulting 2 – Appendix VI; OEM – Appendix XV*). When accompanied with the right regulatory and cultural changes, operators can engage in real-time maintenance contracting processes with MROs (*Consulting 2 – Appendix VIII*). Regardless of this perception, others are doubtful whether Blockchain could really impact the way MROs maintain their customer relationships, since MROs will not suddenly offer a new range of products and services (*Consulting 1 – Appendix IV*). The nature of the discussion will change, but another question remains whether this will actually have an enormous impact (*MRO 1 – Appendix IX*).

5.1.8 Strategic impact of Blockchain on customer channels

Key message: There is consensus among both consulting and industry participants that Blockchain as an aircraft spare part track and trace capability could positively impact MRO customer channels (**Table 23**).

Table 23 – Customer Channels: respondent evaluation

	Consulting 1	Consulting 2	MRO 1	MRO 2	OEM	Total
5: Excellent	0	1 (6%)	0	2 (13%)	0	**3 (19%)**
4: Good	1 (6%)	2 (13%)	2 (13%)	0	2 (13%)	**7 (44%)**
3: Neutral	3 (19%)	1 (6%)	2 (13%)	0	0	**6 (37%)**
2: Poor	0	0	0	0	0	**0**
1: Very poor	0	0	0	0	0	**0**
Total	**4**	**4**	**4**	**2**	**2**	**16**

Key theme identification: To understand why respondents are positive about the impact of Blockchain on the MRO customer channels, the discussion is broken down in one key theme considered important by them (**Table 24**): the Blockchain portal (**H1**).

Table 24 – Customer Channels: frequency of each addressed theme

	Consulting 1	Consulting 2	MRO 1	MRO 2	OEM	Total
H1: Portal	5 (46%)	0	2 (18%)	4 (36%)	0	11 (100%)
Total	**5 (46%)**	**0**	**2 (18%)**	**4 (36%)**	**0**	**11**

Summary: Blockchain can act as a web-based portal that should be seen as an option for operators who can then extract valuable and relevant component data. It is unlikely that Blockchain would replace any existing channel and would provide complementary information. However, Blockchain would be considered as a robust Business to Business channel for MROs to distribute immutable component data.

H1 – Blockchain portal

When aircraft operators must change their component and source new ones, it is possible for them to use Blockchain to find RFID and IoT equipped spare parts and receive the component data through this channel (*Consulting 1 – Appendix I*). This is different from interacting with customer representatives through a call (*Consulting 1 – Appendix I*). In the end, there might be a web-based portal that can be used to show a Blockchain pilot or demo to customers (*Consulting 1 – Appendix II; MRO 2 – Appendix XIII, XIV*), which can be beneficial for MROs that do not already use digital Business-to-Business channels (*Consulting 1 – Appendix III*). Currently customers are approached per aircraft type through different channels that are considered outdated within the MRO industry (e.g. mail, phone) (*Consulting 1 – Appendix IV*). An MRO could create their own personal portal through which they provide an overview of MRO capabilities and offerings, and also use Blockchain as a back-end input to this portal (*Consulting 1 – Appendix IV*). However, it is unlikely that Blockchain will replace any existing channel and would only provide complementary information (*MRO 1 – Appendix X; MRO 2 – Appendix XIV*). An example relates to quality assurance, where a customer support manager must retrieve all component PDFs and distribute it to their clients (*MRO 1 – Appendix XI*). Blockchain as a web-portal should be seen as an option for clients, who can then extract valuable data (*MRO 1 – Appendix XI*). However, to differentiate themselves and provide extra services, the MRO must still contact their clients by phone and mail (*MRO 2 – Appendix XIV*).

5.1.9 Strategic impact of Blockchain on customer segments

Key message: There is consensus among both consulting and industry participants that Blockchain as an aircraft spare part track and trace capability could have neutral impact on MRO customer segments (**Table 25**).

Table 25 – Customer Segments: respondent evaluation

	Consulting 1	Consulting 2	MRO 1	MRO 2	OEM	Total
5: Excellent	0	0	0	0	0	**0**
4: Good	3 (19%)	1 (6%)	0	1 (6%)	2 (13%)	**7 (44%)**
3: Neutral	1 (6%)	3 (19%)	4 (25%)	1 (6%)	0	**9 (56%)**
2: Poor	0	0	0	0	0	**0**
1: Very poor	0	0	0	0	0	**0**
Total	**4**	**4**	**4**	**2**	**2**	**16**

Key theme identification: To understand why respondents are neutral about the impact of Blockchain on the MRO customer segments, the discussion is broken down in one key theme considered important by them (**Table 26**): supply and demand dynamics (**I1**).

Table 26 – Customer Segments: frequency of each addressed theme

	Consulting 1	Consulting 2	MRO 1	MRO 2	OEM	Total
I1: S&D	6 (60%)	2 (20%)	1 (10%)	1 (10%)	0	**10 (100%)**
Total	**6 (60%)**	**2 (20%)**	**1 (10%)**	**1 (10%)**	**0**	**10**

Summary: Blockchain can provide increased market intelligence by capturing component supply and demand conditions at different locations. This provides MROs with the opportunity to open up to a larger market and potentially acquire prospective clients that look for trustworthy MROs. However, it can be questioned whether MROs would actually acquire new customers since: 1) improved trust perception is only marginal; 2) the MRO industry already faces growth, which would most likely not be affected by Blockchain.

I1 – Supply and demand dynamics

When MROs are able to track and trace spare parts through the Blockchain, it is possible to open up to a larger market (*Consulting 1 – Appendix I*). With this increased data transparency, Blockchain can provide insight on part demand based on location (*Consulting 1 – Appendix II*). This, for example, means that Blockchain should be able to capture the demand for wheels and tires at stations with longer runways (*Consulting 1 – Appendix II*). Improved inventory management should help MROs deal with larger market demand when clients arrive at that MRO through a Blockchain search (*Consulting 1 – Appendix II, III*). This increased demand is also from prospective clients who look for trustworthy MROs that use the Blockchain to prove that they engage with only historically clean spare parts (*Consulting 1 – Appendix III*). However, even though transparency would be beneficial for that MRO, it depends on whether the ecosystem would actually support Blockchain (*Consulting 1 – Appendix III*). Regardless of the presence of Blockchain, an MRO will still be subject to the market supply and demand dynamics when they must acquire components (*Consulting 1 – Appendix IV*). Demand is continuously growing, which raises the doubt whether the MRO business is under pressure (*Consulting 2 – Appendix V*). Therefore, at the end if the value proposition and competitive position improves, then MROs would be able to acquire new clients (*Consulting 2 – Appendix V; MRO 2 – Appendix XIV*). However, it is doubtful whether this alone will help MROs acquire new customers, since relationships are based upon trust, which the Blockchain should contribute to marginally (*MRO 1 – Appendix X*).

5.1.10 Conclusion

The first part of the results focused on the impact of Blockchain as an aircraft spare part track and trace capability on the MRO business model. These results were acquired by coding the interviews and analysing the surveys that were given during these interviews. These results address the third research question:

How does Blockchain as an aircraft spare part track and trace capability impact the MRO business model?

Through sixteen interviews with consulting and industry participants, it is possible to conclude that the impact of Blockchain on the MRO business model is considered positive. It is assumed that the average impact is considered positive if it exceeds a threshold of 3,5 (**Figure 23**). The logic behind this assumption is that most average scores range between 3 and 4, with 3 valued as a neutral and 4 as a positive impact. A decision was made to evaluate the impact as positive when it passes the average of the two values. Critical reviewers could lower the threshold.

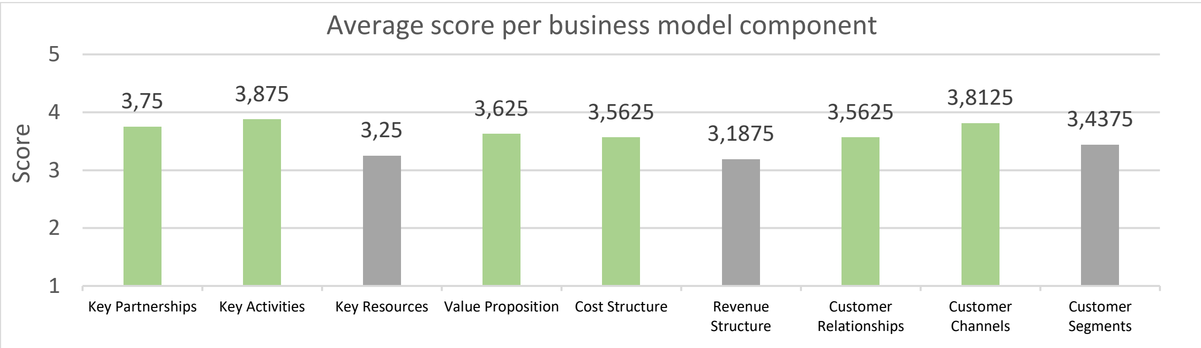

Figure 23 – Quantitative overview: impact of Blockchain on the MRO business model

The figure above can be translated into the MRO Business Model Canvas, which is a different way of presenting the quantitative results (**Figure 24**).

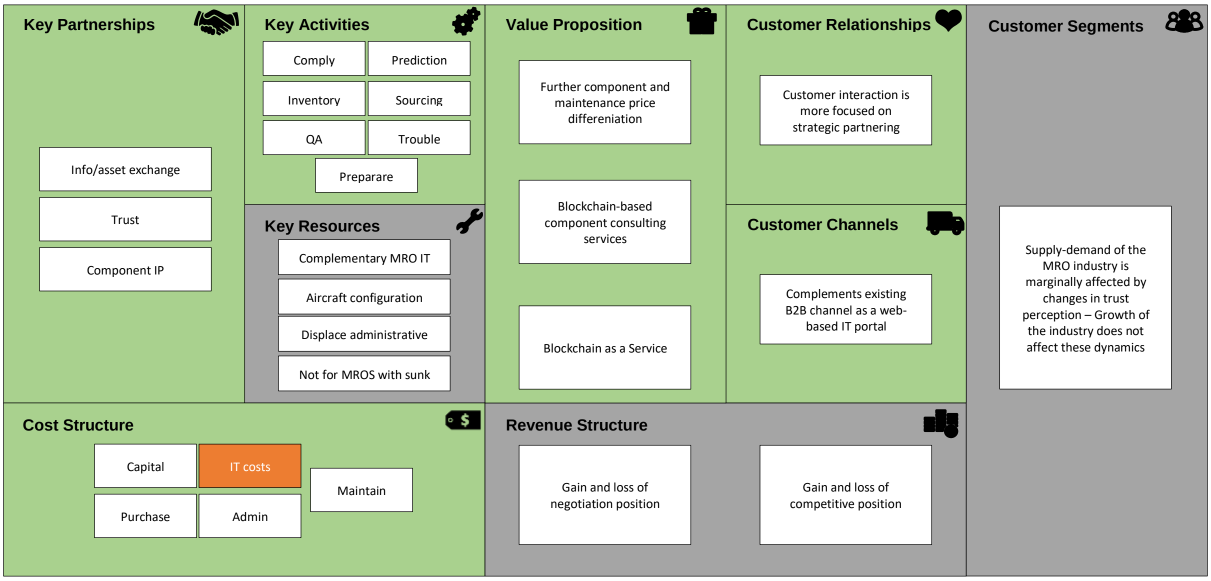

Figure 24 – MRO Business Model Canvas: Blockchain impact

Unfortunately, the quantitative results do not provide sufficient insight on why and how Blockchain could have a certain impact on MRO business model components. A table of all strategic impact areas are included, together with supporting and counter argument behind Blockchain (**Table 27**). In this table, 1) aircraft spare parts are shortened to parts; 2) next to the business model the quantitative result is shown (**see figure 24**).

Table 27 – Qualitative overview: impact of Blockchain on the MRO business model

Strategic impact area	Supporting argument	Counter argument
3.8 Key partnerships		
A1: Information and asset exchange	Standardise data exchange Reduce exchange at outsource Synchronise part data Real-time part data Confidence in part data	Leakage weakens partnerships Holistic view cause some to lose Parties might not want to share
A2: Supply chain and ecosystem trust	Trust in other parties Trust in part legitimacy Trust in part dataset	Trust is needed for Blockchain Trust in MROs already expected Trust in data integrity required
A3: Component IP control	Increase access to OEM IP	OEMs incentivised to control
3.9 Key activities		
B1: Regulatory compliance	Acquire part data faster	Parties may not share the data
B2: Predictive maintenance	Draw on global reliability data	Blockchain scalability
B3: Inventory management	Global view on part availability	Requires predictive maintenance
B4: Component sourcing	Flexible sourcing strategies	
B5: Quality assurance	Reduce paperwork	Storage problem
B6: Maintenance troubleshooting	Reduce part replacement	
B7: Maintenance execution	Improve preparation	No impact on core maintenance
3.3 Key resources		
C1: Physical resources	Blockchain complements IT Utilise smart contracts Still work with paperwork	Challenge to integrate with IT Immutability problem Regulatory opposition
C2: Intellectual resources	Aircraft configuration control Reduced counterfeit parts Improved part intelligence	Data consistency is difficult Requires widespread support Commoditised part analytics
C3: Human resources	Reduce administration	Back-office employee resistance Invest in IT/Business experts
C4: Financial resources	Large MROs can support effort Small MROs in a better position	Large MROs face sunk costs Difficult business case
3.6 Value proposition		
D1: MRO core value proposition	Improve price differentiation	Core proposition not affected
D2: Ecosystem-based analysis	Consultancy to authorities Consultancy to operators	OEMs monetise data feeds Easily commoditised
D3: Blockchain as a Service	Subscription revenues	Requires widespread support Conflicts Blockchain philosophy
3.6 Cost structure		
E1: Inventory costs	Through optimised inventory	Parties may not share the data Required predictive maintenance Blockchain scalability
E2: Part purchase costs	Through improved sourcing	
E3: IT costs		Short-term IT transition Long-term IT support Unknown Blockchain cost model
E4: Administrative costs	Through reduced labour Through reduced interactions Through reliable tracking	
E5: Maintenance costs	Through improved part data	Applicable in only few situations
3.2 Revenue structure		
F1: Negotiation position	Same: operator in emergency Gain: leverage around OEMs	Loss: real-price transparency Loss: part cycle transparency Loss: use of shared data
F2: Competitive position	Gain: ecosystem-based analysis Gain: if adopted by few Same: if adopted by industry	Loss: forced to switch Loss: exposure to smaller MROs
3.6 Customer relationships		
G1: Customer interactions	Less bargaining and disputes Reduce operator frustration	Nature of relationships same Impact is questionable
3.8 Customer channels		
H1: Blockchain portal	Distribute part data to operator Act as a robust B2B channel	Unlikely to replace channels
3.4 Customer segments		
I1: Supply and demand dynamics	Open up to a larger market Gain clients looking for trust	Industry already faces growth Trust perception is marginal

5.2 Robustness of the MRO business model

Introduction: The second part of the results focused on the robustness of the MRO business model when it is confronted against the main stress factors identified in chapter 3: degree of data exposure; degree of network support; degree of regulatory support. After addressing the third research question, a workshop session occurred with an independent MRO. These results were acquired by reviewing audio files and post-it notes. Based on these results, a heat map is constructed to highlight how the stress factors affect the MRO business model (**5.2.1**). To evaluate the robustness of the MRO business model, it is necessary to engage in a sub-view (**5.2.2**) and pattern analysis (**5.2.3**) of the heat map. These results provide answer to the fourth research question (**5.2.4**):

How robust are MRO business models when it is confronted against Blockchain as an aircraft spare part track and trace capability?

Key message: A sub-view analysis on the rows of the heat map shows that the MRO business model is considered robust, since 1) two components are robust in all scenarios (key activities, customer channels); 2) five components are not robust in one out of six scenarios (key partnerships, key resources, value proposition, customer relationships, customer segments); 3) only two components are not robust in two out of six scenarios (cost structure, revenue structure). A sub-view analysis on the columns of the heat map shows that the MRO business model cannot be pressured by Blockchain alone, but rather by the premise of extensive data exchange. A pattern analysis of the heat map show that MROs should opt for a regulatory-backed Blockchain solution where only traceability and logbook data are exchanged throughout the entire industry. Additionally, the pattern analysis show that four business model components are consistent in all outcomes of data exposure (key activities, cost structure, customer relationships, customer channels) and two business model components in all outcomes of regulatory support (revenue structure and customer relationships). A best-case scenario evaluation identifies three business model components that are internally inconsistent throughout the scenarios (value proposition, revenue structure and customer relationships).

5.2.1 Heat map construction

As aligned with the Business Model Stress Test methodology, after evaluating the impact of Blockchain on the MRO Business Model it is necessary to evaluate business model robustness. This is done by filling in the MRO Business Model Heat Map template, which confronts horizontally positioned business model components against vertically positioned stress factor outcomes (**Table 28**).

Table 28 – MRO Business Model Heat Map template

	Scenario	Blockchain as an aircraft spare part track and trace capability					
	Stress factors	Data exposure		Network support		Regulatory support	
	Outcomes	Limited	Sensitive	Limited	Industry	Limited	Support
Business model components	Key Partnerships						
	Key Activities						
	Key Resources						
	Value Proposition						
	Cost Structure						
	Revenue Structure						
	Customer Relationships						
	Customer Channels						
	Customer Segments						

Based upon interview data and a stress test workshop with an independent MRO, it was possible to fill in the MRO Business Model Heat Map (**Table 29**). The motivation and justification behind this heat map is included in the appendix (**Appendix XVII**).

Table 29 – MRO Business Model Heat Map

	Scenario	Blockchain as an aircraft spare part track and trace capability					
	Stress factors	Data exposure		Network support		Regulatory support	
	Outcomes	Limited	Sensitive	Limited	Industry	Limited	Support
Business model components	Key Partnerships	1A	1B	1C	1D	1E	1F
	Key Activities	2A	2B	2C	2D	2E	2F
	Key Resources	3A	3B	3C	3D	3E	3F
	Value Proposition	4A	4B	4C	4D	4E	4F
	Cost Structure	5A	5B	5C	5D	5E	5F
	Revenue Structure	6A	6B	6C	6D	6E	6F
	Customer Relationships	7A	7B	7C	7D	7E	7F
	Customer Channels	8A	8B	8C	8D	8E	8F
	Customer Segments	9A	9B	9C	9D	9E	9F

5.2.2 Sub-view analysis

The sub-view analysis adopts two perspectives: 1) a business model component perspective to identify why some business model components appear more robust than others; 2) a stress factor perspective to identify which stress factors have the largest impact.

Business Model Component perspective

A sub-view perspective on the rows of the heat map shows the robustness of each MRO business model component. This perspective shows that in general the MRO business model is considered robust, since:

- Two business models are robust in all scenarios (Key activities, customer channels);
- Five business models are not robust in one out of six scenarios (Key partnerships, key resources, value proposition, customer relationships, customer segments);
- Two business models are not robust in two out of six scenarios (Cost structure, revenue structure).

What this discovery shows is that the MRO will face a trade-off when it considers Blockchain to exchange component data: the importance of improved maintenance activities against the potential risk they face for its cost and revenue structure.

Stress Factor perspective

A sub-view perspective on the columns of the heat map shows the severity of the impact of each stress factor. This perspective shows that in general a few stress factors can lead to more favourable scenarios than others:

- Two out of six scenarios have no negative implications for the MRO business model (limited data exposure, full regulatory support);
- One out of six scenarios have more positive than neutral or negative implications for the MRO business model (widespread network support);
- Two out of six scenarios have more neutral than positive or negative implications for the MRO business model (limited network support, limited regulatory support);
- One out of six scenarios have more negative than neutral or positive implications for the MRO business model (sensitive data exposure).

What this discovery shows is the general premise that the MRO business model cannot be pressured by Blockchain alone. It is the premise that excessive data exchange could have major implications for the MRO business model, whether this is facilitated by Blockchain or another technology. Additionally, given the importance of the network effect and the regulatory nature of aircraft maintenance, only when widespread industry and regulatory support is present MROs would be able to perceive noticeable improvements to their business model.

5.2.3 Pattern analysis

The pattern analysis is focused on the colouring pattern of the heat map in order to identify a few important key elements: 1) preferred outcome for the MRO business model; 2) consistency and 3) inconsistency of each business model component.

Preferred outcome for the MRO business model

A pattern analysis show that MROs should take a certain position in the establishment of the Blockchain in order to acquire the most favourable outcome. Since these uncertainties are path-dependent outcomes that follow the decisions made by a consortium of MROs, OEMs and operators, MROs should opt for a solution where:

- Only traceability and logbook data are exchanged;
- Throughout the entire industry with other MROs, OEMs and operators;
- With regulatory support from EASA and FAA, guided by IATA.

If MROs are forced by regulatory institutions to share more data on the Blockchain than desired, their MRO business model is pressured. This would raise the question whether MROs would actually want to participate with Blockchain. If MROs share a limited amount of data without the support of the industry or regulation, the Blockchain will not yield as a robust business model solution. If MROs successfully establish a Blockchain consortium throughout the industry without regulatory initiation, it is important to find support from EASA or FAA when the IATA declared the consortium as an industry best practice standard.

Consistency of each business model component

There are no business model components that are not robust in all future scenario, as made evident by the lack of double-red extreme scenarios.

There are a few business model components that are consistently impacted in all outcomes of data exposure:

- Key activities: Both low and high degree of data exposure can help MROs improve their capabilities, depending on how an MRO takes advantage of the data on the Blockchain;
- Cost structure: Even with limited component logbook data, MROs can still find cost reduction opportunities in the field of quality and assurance;
- Customer relationships: With both low and high amount of data exposure, MROs show operators that they are transparent and encourage their client to engage in Big Data.
- Customer channels: Regardless of the amount of data exposure, the Blockchain would eventually be perceived as a complementary Business-to-Business channel.

There are a few business model components that are consistently impacted in all outcomes of regulatory support:

- Revenue structure: The ability to acquire revenues from Blockchain depends on the ability of the MRO to acquire new capabilities from the increased data provision.
- Customer relationships, channels and segments: Since regulatory institutions are not allowed to affect the business dynamics between an MRO and their customers, these business model components are equally unaffected by degree of regulatory support.

Inconsistency of each business model component

To evaluate the inconsistency of each business model component, the best-case scenario is evaluated where limited data is shared through Blockchain with industry and regulation:

- Value proposition: MROs can improve their value proposition to regulators and differentiate themselves using Blockchain data if they have the translating capabilities, which could potentially become commoditised.
- Revenue structure: Even though Blockchain is a unique selling point that allow MROs to improve their negotiation and competitive position, MROs are responsible for extracting this value when they are one of the many Blockchain participants.
- Customer relationships: Even though Blockchain can help MROs show transparency towards operators, this contribution might be diminished when all parties are able to take advantage of Blockchain.

5.2.4 Conclusion

The second part of the results focused on the robustness of the MRO business model when it is confronted against the main stress factors identified in chapter 3: degree of data exposure; degree of network support; degree of regulatory support. After addressing the third research question, a workshop session occurred with an independent MRO. These results were acquired by reviewing audio files and post-it notes. By constructing a heat map and engaging in a sub-view and pattern analysis, the results address the fourth research question:

How robust are MRO business models when it is confronted against Blockchain as an aircraft spare part track and trace capability?

Through a Business Model Stress Test workshop, the MRO Business Model Heat Map has been completed (**Table 29**).

Table 29 – MRO Business Model Heat Map

	Scenario	Blockchain as an aircraft spare part track and trace capability					
	Stress factors	Data exposure		Network support		Regulatory support	
	Outcomes	Limited	Sensitive	Limited	Industry	Limited	Support
Business model components	Key Partnerships	1A	1B	1C	1D	1E	1F
	Key Activities	2A	2B	2C	2D	2E	2F
	Key Resources	3A	3B	3C	3D	3E	3F
	Value Proposition	4A	4B	4C	4D	4E	4F
	Cost Structure	5A	5B	5C	5D	5E	5F
	Revenue Structure	6A	6B	6C	6D	6E	6F
	Customer Relationships	7A	7B	7C	7D	7E	7F
	Customer Channels	8A	8B	8C	8D	8E	8F
	Customer Segments	9A	9B	9C	9D	9E	9F

A sub-view analysis on the rows of the heat map shows that the MRO business model is considered robust, since 1) two components are robust in all scenarios (key activities, customer channels); 2) five components are not robust in one out of six scenarios (key partnerships, key resources, value proposition, customer relationships, customer segments); 3) only two components are not robust in two out of six scenarios (cost structure, revenue structure). This shows that the MRO faces a trade-off between its key maintenance activities and its cost and revenue structures. A sub-view analysis on the columns of the heat map shows that the MRO business model cannot be pressured by Blockchain alone, but rather by the premise of extensive data exchange. Additionally, given the importance of the network effect and regulatory nature of the MRO industry, MROs can only perceive noticeable improvements to their business model when the industry and institutions supports Blockchain.

A pattern analysis of the heat map show that MROs should opt for a regulatory-backed Blockchain solution where only traceability and logbook data are exchanged throughout the entire industry. Additionally, the pattern analysis show that four business model components are consistently impacted in all outcomes of data exposure (key activities, cost structure, customer relationships, customer channels) and two business model components in all outcomes of regulatory support (revenue structure and customer relationships). Finally, by evaluating the best-case scenario, where limited data is shared through Blockchain with industry and regulatory support, three business model components are identified that are internally inconsistent throughout the scenarios (value proposition, revenue structure and customer relationships).

5.3 Feasibility of the Aviation Blockchain consortium

Introduction: The third part of the results focused on the feasibility of the Aviation Blockchain consortium, since this is considered important by interviewees. These results represent additional themes that follow the interview coding procedure. Throughout the interviews, the participants consistently took the initiative to raise three main factors regarding the feasibility of the Blockchain consortium: the problem of data ownership (**5.3.1**); the need to incentivise parties (**5.3.2**); opposition from authorities (**5.3.3**). By discussing these additional results, it is possible to provide answer to the fifth research question (**5.3.4**).

How feasible is it for the aviation industry to consider a Blockchain consortium for the purpose of aircraft spare part management?

Key message: The establishment of an Aviation Blockchain consortium faces three primary problems: the problem of data ownership; the need to incentivise parties; the opposition from regulatory institutions. The problem is that different parties claim ownership over component data, which will not be necessarily solved with Blockchain. The initiation and ownership of the Blockchain should be distributed between industry participants and institutions in order to prevent opportunism. However, a solution in which no party owns the data may not get accepted by regulators, since they are concerned about component data responsibility, location and ownership. This is one reason why the regulator will not be involved in the early phase until Blockchain emerges as an industry standard, propelled and initiated by key industry participants and IATA. In a late stage, the EASA or FAA may be involved in order to maintain oversight over the Blockchain ecosystem and assure that all participants have the necessary capabilities to participate. Until industry participants and institutions are convinced that they can use Blockchain to remotely monitor and audit components, they will continue to work with physical paperwork. These problems are evident examples of the fragmented nature of the aviation industry, which challenge the establishment of a Blockchain consortium.

5.3.1 Feasibility factor #1: The problem of data ownership

Data ownership is considered important, since lack of ownership makes it difficult to allocate responsibility of data integrity to parties (*Consulting 1 – Appendix II*). This problem extends for the aviation industry where the location of data storage is relevant, especially when data generated in one country is in conflict with the country where the data is actually maintained (*Consulting 1 – Appendix II*). Furthermore, in the aviation industry all parties claim ownership of component data for different reasons (*Consulting 2 – Appendix V*):

- MROs: Generate maintenance data during component maintenance activities;
- OEMs: Manufacture the components and provide warranties and guarantees;
- Aircraft operators: Responsible to prove airworthiness.

The problem of data responsibility, location and ownership is not necessarily solved with Blockchain, especially since the interaction and exchange between these parties are limited and political (*Consulting 2 – Appendix V; MRO 1 – Appendix IX*). Based on this premise, interviewees raised two major concerns, which includes:

- Initiation of the Blockchain consortium;
- Ownership of the Blockchain ownership.

For each concern, interviewees discussed insight on what would happen in different scenarios:

- When initiation/ownership is allocated to industry participants (MRO/OEM/operator);
- When initiation/ownership is allocated to industry institutions (IATA/EASA/FAA);
- When initiation/ownership is allocated to industry participants and institutions.

The next parts are structured to discuss how these scenarios manifest for the main concerns.

Concern 1: Initiation of the Blockchain consortium

Scenario 1A: Initiation from the industry participants

Similar to what happened with the establishment of an industry-wide ticketing system, it is believed that the Blockchain initiation should come from the industry where a few large industry key players collaborate on its construction (*Consulting 1 – Appendix IV*):

- MROs: A large MRO could partner with another MRO, where it is important to engage with a competitor in order to set an example to the industry (*MRO 1 – Appendix X*).
- OEMs: A large OEM is more likely to force aircraft operators to switch to the Blockchain than an MRO, since they are the first step in the chain (*Consulting 2 – Appendix VI; MRO 2 – Appendix XIV*);
- Aircraft operator: This could be initiated by a large aircraft operator that can leverage MROs and OEMs to move onto the Blockchain, which might not be interoperable with other operators (*Consulting 2 – Appendix VI*).

Scenario 1B: Initiation from the industry institutions

The aviation industry is a relatively fragmented industry with players that depend on mutual access to industry platforms, which are efforts that are driven by IATA to ensure industry standardisation (*Consulting 2 – Appendix VI*). Even though industry players could initiate the Blockchain, it is necessary to involve IATA or regulators that sets these standards (*Consulting 2 – Appendix VI*). IATA will most likely be able to succeed in this initiative, since IATA is directed by shareholders and directors that comprise of aircraft operators (*Consulting 2 – Appendix VI*). For that reason, it is logical to assume that authorities and regulatory bodies are not directly included in this initiative (*Consulting 2 – Appendix VI*). These regulators might not even participate in the Blockchain until the system is established as an industry standard (*Consulting 2 – Appendix VI*).

Scenario 1C: Initiation from both industry participants and institutions

Another scenario is to consider a joint-initiation from a large aircraft operator, OEM and regulator (e.g. EASA, FAA), who together must determine (*Consulting 2 – Appendix VII*):

- Which component related data and processes must be shared and managed;
- Which party owns the component data IP and which parties are able to access it.

What might emerge is a race between 1) industry participants that start understanding the value of Blockchain to improve spare part management and; 2) regulatory bodies that start understanding the value of Blockchain to support component safety requirements (*OEM – Appendix XVI*). The industry participants would rely on their market presence to facilitate confidence to move clients onto the Blockchain and guide regulatory bodies in this process (*OEM – Appendix XV, XVI*). In contrast to an established partnership between an operator and its MRO providers, companies that do not have this pre-existing relationship might not be able to leverage Blockchain in their ecosystem (*OEM – Appendix XV*). The regulatory bodies should support and mandate the initiative from the very beginning by emphasising the importance of component data visibility, given its safety improvements (*Consulting 2 – Appendix VII, VIII; MRO 2 – Appendix XIII, XIV*). However, it is difficult to see the regulator participating in the early phases of this initiative, since they emphasise the importance of paper records and hardcopy signatures (*Consulting 2 – Appendix VII*).

Concern 2: Ownership of the Blockchain consortium

Scenario 2A: Allocating ownership to the industry participants

Currently, the ownership of existing component data is fragmented: MROs own component maintenance and reliability data; OEMs own component data feeds; aircraft operators own data on aircraft and component availability (*Consulting 2 – Appendix VII; MRO 1 – Appendix X, XI*). It is difficult to understand how this fragmented ownership can be translated to a Blockchain-based ecosystem, where no party would own the data (*MRO 1 – Appendix IX*).

Scenario 2B: Allocating ownership to the industry institutions
It is believed that a third party (e.g. regulator) should maintain oversight over the Blockchain ecosystem without providing any form of input (*Consulting 1 – Appendix II, III; MRO 2 – Appendix XIII, XIV*). When regulators are part of the Blockchain, they have full insight on whether any component related action is done within regulatory limits (*Consulting 1 – Appendix II*). Their primary role includes (*Consulting 1 – Appendix II; MRO 2 – Appendix XIV*):

- Assuring that only trusted parties would enter the Blockchain;
- Assuring that no party would pollute the Blockchain;
- Assuring that each party follow the right application processes;
- Assuring that each party have the right capabilities to participate;
- Assuring that each party does not engage in unfair collusion and price agreements.

Scenario 2C: Allocating ownership to both industry participants and institutions
The idea of allocating Blockchain ownership to a specific party conflicts the philosophy behind Blockchain, where ownership is shared throughout the ecosystem (*MRO 1 – Appendix X; MRO 2 – Appendix XIII*). It is not desirable to allocate ownership to an industry participant, since it would not be fair for that participant to be responsible of the data integrity of the entire network (*MRO 1 – Appendix X*). It would also not be fair for the network, since all participants would be vulnerable to opportunistic actions of that owner (*Consulting 1 – Appendix III*). One example is when ownership would be allocated to an OEM, who can force MROs out of the market by excluding them from the Blockchain (*MRO 2 – Appendix XIII, XIV*). In the scenario where ownership is shared, industry participants cannot reap benefits from owning a Blockchain platform, and regulators would only be connected to the network to see what happens with the components (*Consulting 1 – Appendix III*). However, a solution in which no party owns the data may not get accepted by regulators, since they are concerned about data responsibility, location and ownership (*Consulting 2 – Appendix V; MRO 1 – Appendix IX*).

5.3.2 Feasibility factor #2: The need to incentivise parties

The value of Blockchain is characterised by the network effect, which increases with the number of industry participants (*Consulting 1 – Appendix I; MRO 2 – Appendix XIII*). Since this research focused on incentivising MROs to participate in the ecosystem, it still raises two concerns:

- OEMs must be incentivised to participate in the Aviation Blockchain consortium.
- Operators must be incentivised to participate in the Aviation Blockchain consortium.

Concern 1: Incentivising OEMs to participate in the Aviation Blockchain consortium

There are different factors that incentivise OEMs to not participate in the Aviation Blockchain consortium:

- Loss of IP control: OEMs that operate in the component aftermarket may not want to lose control over their IP (e.g. APU) due to Blockchain (*Consulting 2 – Appendix VI; OEM – Appendix XV*);
- Reduction of component usage: OEMs that participate in a Blockchain environment witness a reduction of overall component usage due to MROs and operators that evaluate their minimum stock requirements (*Consulting 2 – Appendix VIII; MRO 1 – Appendix X*);
- Protection of component data feeds: OEMs currently monetise and compete on component data feeds, which they might not want to open up on the Blockchain (*Consulting 2- Appendix VII; MRO 2 – Appendix XIII*);
- Loss of negotiation position: OEMs that have a negotiation position around part recommendations might lose this edge when MROs and operators leverage around the OEM using immutable Blockchain component data (*MRO 1 – Appendix X*).

However, interviewees believe it should be possible to incentivise OEMs to participate in the Aviation Blockchain consortium:

- Improved external IP access: Despite losing control over their own IP, OEMs can access external IPs used by MROs through the Blockchain (*OEM – Appendix XV*);
- Ecosystem-based analysis: Using component data for the whole ecosystem, OEMs should be able to improve their parts databases (*Consulting 1 – Appendix II*);
- Improved trust: The OEM that engages earlier with Blockchain will be trusted more over others (*Consulting 1 – Appendix III*) and if they claim ownership they can reap benefits in terms of platform revenues (*Consulting 1 – Appendix IV*).

Concern 2: Incentivising aircraft operators to participate in the Aviation Blockchain consortium

There are different factors that incentivise aircraft operators to have limited participation in the Aviation Blockchain consortium:

- Willingness to share data: Even though operators are incentivised to share data on component availability (*Consulting 2 – Appendix VIII; MRO 1 – Appendix IX*), it can be questioned whether they will actually share component availability data (*MRO 1 – Appendix X*).

However, interviewees believe it should be possible to incentivise aircraft operators to participate in the Aviation Blockchain consortium:

- Optimal data exchange: By improving component data exchange with MROs, operators can improve the day-to-day aircraft operations (*Consulting 2 – Appendix VIII; OEM – Appendix XVI*).
- Improved negotiation position: Blockchain can help operators improve their negotiation position against opportunistic MROs (price, cycle optimisation) and OEMs (part recommendation) in a transparent component aftermarket (*Consulting 1 – Appendix I, II, IV; Consulting 2 – Appendix V, VII, VIII; MRO 1 – Appendix X*).

5.3.3 Feasibility factor #3: The opposition from authorities

Without the support of the authorities, it is difficult to establish a Blockchain consortium that would be accepted as an industry standard (*Consulting 2 – Appendix V*). Not only is it possible to identify power political conflicts between industry participants, it is also possible to identify this between industry institutions (*Consulting 2 – Appendix V*). Industry participants typically underestimate the opposition from industry institutions regarding new technologies, especially in the aviation industry where safety is a priority (*Consulting 2 – Appendix V*). The difficulty to introduce innovation to authorities such as EASA and FAA is the main reason why IATA might conflict with the authorities (*Consulting 2 – Appendix V*). It shows that industry institutions are as fragmented as industry participants (*Consulting 2 – Appendix VI*). The problem is that there are many regulators with their own vision over how Blockchain should be established and designed (*MRO 1 – Appendix IX*). EASA and FAA are very fragmented, since they are driven by different decisions (e.g. US congress/EU commission respectively) (*MRO 1 – Appendix IX*). The fragmented nature of industry institutions does not mean that Blockchain could not succeed in the aviation industry (*OEM – Appendix III*). The regulatory nature of the aviation industry, where industry participants are expected to emphasise scrutiny in its processes for the purpose of safety, actually underscores the need of these participants to consider Blockchain (*OEM – Appendix XV, XVI*). Authorities can be convinced in Blockchain, since they can remotely manage, monitor and audit components (*MRO 2 – Appendix XIII*).

5.3.4 Conclusion

The third part of the results focused on the feasibility of the Aviation Blockchain consortium, since this is considered important by interviewees. These results represent additional themes that follow the interview coding procedure. Throughout the interviews, the participants consistently took the initiative to raise three main concerns regarding the establishment of a Blockchain consortium: the problem of data ownership; the need to incentivise parties; opposition from authorities. By discussing these additional results, it is possible to address the fifth and final research question:

How feasible is it for the aviation industry to consider a Blockchain consortium for the purpose of aircraft spare part management?

An overview is provided to show the main concerns that oppose Blockchain feasibility and how it is manifested through different problems (**Table 30**).

Table 30 – Aviation Blockchain consortium feasibility evaluation

Feasibility factor	Concern	Problem
Problem of data ownership	Blockchain ownership Blockchain initiation	Parties claim ownership Parties present opportunism
Need to incentivise parties	Opposition from OEMs Opposition from Operators	Change in industry dynamics
Opposition from institutions	Opposition from EASA/FAA	Concern about data protocol

The feasibility of the Blockchain consortium depends on whether the aviation industry can address the three main feasibility factors. Unfortunately, the establishment of a Blockchain consortium faces different problems that make it difficult to address the problem. The first problem is that industry participants already claim ownership over component data, which will not necessarily be solved with Blockchain since interaction and exchange between and among industry participants (e.g. MRO/OEM/operator) and institutions (e.g. IATA/EASA/FAA) are limited and political in nature. The second problem is that industry participants possess an opportunistic nature: if Blockchain initiation and ownership is allocated to a specific party (e.g. OEM), they can exclude opposite parties (e.g. competitors) from entering the Blockchain. The third problem is that industry participants are incentivised to not enter the Blockchain consortium, since they might lose negotiation and competitive position; lose component IP control; or may not be willing to open up their component data on Blockchain. The fourth problem is that a Blockchain solution, where no party owns the data, will simply not be accepted by regulators that are concerned about data responsibility, location and ownership.

These problems are evident examples of the fragmented nature of the aviation industry, which might make it difficult to establish a Blockchain consortium. In order for the Blockchain consortium to be considered a feasible consideration, key industry parties must determine which component data is shared on the Blockchain and who would own that respective data segment. This shows that the initiation and ownership of the Blockchain should be distributed between industry participants and regulatory institutions in order to prevent opportunism in this stage. However, since a solution in which no party owns the data may not get accepted by regulators, it may be necessary to exclude authorities from the early stage of Blockchain adoption. It is necessary that Blockchain must first emerge as an industry standard, propelled and initiated by key industry participants and IATA. In a later stage, the EASA or FAA may be involved in order to maintain oversight over the Blockchain ecosystem and assure that all participants have the right capabilities to not pollute the ecosystem. However, until authorities are convinced that they can use Blockchain to remotely monitor and audit components, they will continue to emphasise paper records and signatures.

6 CONCLUSION

The sixth chapter first addresses the five research questions proposed in the first chapter of the thesis (6.1). Based on these conclusions, the chapter then discusses the research problem, research objective and Blockchain limitations (6.2). The deliverable of this chapter are managerial recommendations that prepare MROs for Blockchain and academic recommendations for future research (6.3).

6.1 CONCLUSION

This paragraph provides an answer to the five research questions that were proposed in the first chapter, which combined should address the main research objective. As made evident throughout the research, in order to address this objective, it is necessary to discuss: how Blockchain can be used to track and trace aircraft spare parts (6.1.1); how MRO business models could be systematically evaluated and confronted (6.1.2); how Blockchain as an aircraft spare part track and trace capability could impact the MRO business model (6.1.3); how robust the MRO business model is when it is confronted against stress factors (6.1.4); how feasible and viable it is for the aviation industry to consider a Blockchain consortium (6.1.5).

6.1.1 Blockchain to track and trace aircraft spare parts

Based on desk research, it is possible to address the first research question:

How is Blockchain capable to track and trace the movement, modification and maintenance of aircraft spare parts and communicate it throughout the whole aviation supply chain?

Through theoretically grounded research, a Blockchain use case was hypothesised on the premise that it can improve aviation supply chain and ecosystem transparency. With the capability to hash both tangible (e.g. aircraft spare parts) and intangible (e.g. Certificate of Airworthiness) assets, Blockchain can be extended to the MRO industry as an aircraft spare part track and trace capability. This concept is already used to track and trace cars (e.g. Bitcar), coffee beans (e.g. Tony Chocolonely) and diamonds (e.g. Everledger). The hashed aircraft spare parts would be recognised as smart properties and receive a unique identification code that makes it possible to track, control and exchange its ownership. These transactions will be recognised as a block by the Blockchain network and added to the previous chain of blocks once the network reaches consensus to validate the transaction. When it is validated, any participating member (e.g. MRO, OEM, operator, regulator) would immediately be able to audit the block to verify changes in the aircraft spare part movement, ownership and condition.

If any information is shared for the purpose of tracking and tracing aircraft spare parts, it is important to assure that the Blockchain traceability data is Spec 2000 compliant. This means that the Blockchain must at the very least acquire and present information on component CAGE code, part serial number, current part number, action company, action date and action codes. Additionally, the Blockchain could acquire information on component limitations, status change, logbooks, Service Bulletins and product attributes. With this, the Blockchain can function as an inter-organisational digital distributed component logbook among known and trusted supply chain participants in a controlled network where component RFID-based traceability data and IoT-based reliability data can be exchanged.

It is likely that the Blockchain will be used to only track and trace rotable aircraft spare parts (e.g. wheel/landing gear). These components are more complex and critical to flight operations, which classifies them as financially valuable assets. Additionally, these components have an indefinite lifecycle compared to their repairable and expendable counterparts, which means that they can often enter maintenance, repair and overhaul. It is unlikely that the aviation industry will track individual expendable parts (e.g. lamps) but might consider tracking and tracing a box full of repairables or expendables.

6.1.2 Systematic MRO Business Model evaluation

Based on desk research, it is possible to address the second research question:

How is it possible to systematically evaluate the robustness of MRO business models when it is confronted against Blockchain as an aircraft spare part track and trace capability?

Desk research on business model identifies Business Model Stress Test as the only academic method to systematically evaluate business model robustness in early stages of strategic formulation to cope with uncertain future scenarios. Unfortunately, this method is qualitative in nature, with no quantitative assumptions to support the research. The validity and reliability of the test therefore depend on the quality of the business model and the selected stress factors. Luckily, the method is ontology-agnostic, which means that any design method can be used to describe the business model. Since changes in aircraft spare part information exchange practices can directly or indirectly impact aircraft maintenance activities, the decision was made to focus on the MRO business model. Among the four identified business model ontologies, the decision was made to adopt the Business Model Canvas, since the model is exhaustive in covering different business model components; is applicable in any context; is easy to analyse and communicate; builds upon previous work. The figure below shows an overview of the canvas (**Figure 21**), based on paragraph 3.2.

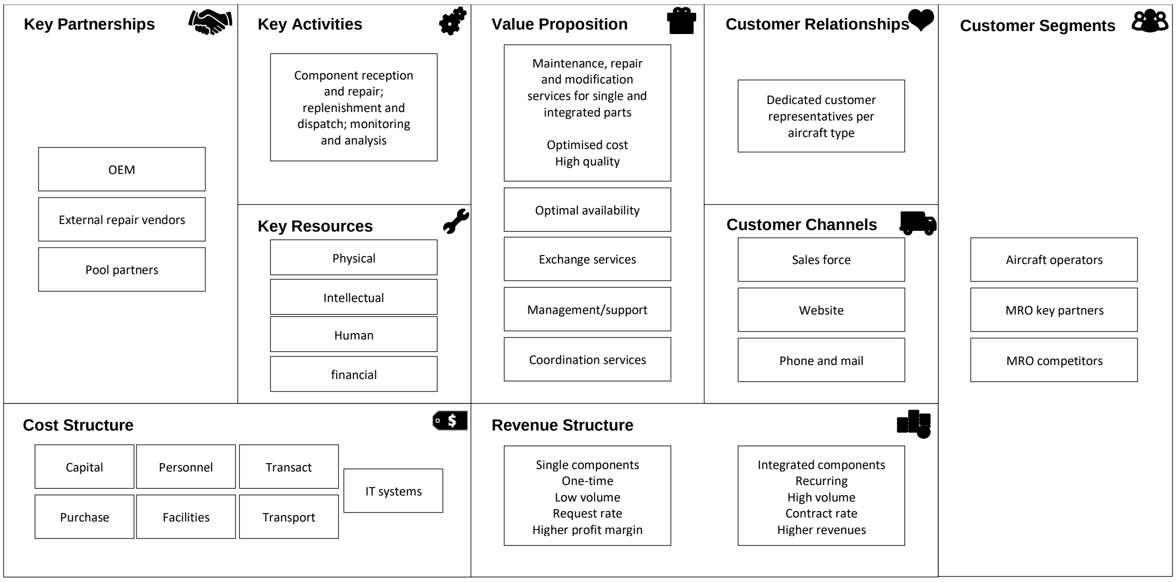

Figure 21 – MRO Business Model Canvas

As discussed in paragraph 3.3, through desk research on Blockchain and through interviews, three stress factors are formulated: extent of data exposure; extent of network support; extent of regulatory support. These factors are used to later evaluate whether the MRO business model is robust when they are exposed to these uncertainties in a Blockchain-based environment. The outcome of that part of the Business Model Stress Test is a heat map, where business model components are confronted against stress factors.

To acquire data on the relationship between Blockchain as an aircraft spare part track and trace capability and the MRO business model components, as well as data on how this impact could fluctuate when moderated by different stress factors, it is necessary to develop a research protocol. The concurrent nested mixed methods design improves research validity and reliability by developing qualitative and quantitative data collection, data analysis and Business Model Stress Test strategies. This is possible, since these strategies are based upon a conceptual model that considers a theoretical framework proposed in chapter 2 and an evaluation methodology proposed in chapter 3. By discussing the protocol in depth, researchers can replicate the results of this research.

6.1.3 Strategic impact of Blockchain on the MRO business model

The first part of the results focused on the impact of Blockchain as an aircraft spare part track and trace capability on the MRO business model. These results were acquired by coding the interviews and analysing the surveys that were given during these interviews. These results provide answer to the third research question:

How does Blockchain as an aircraft spare part track and trace capability impact the MRO business model?

Through sixteen interviews with consulting and industry participants, it is possible to conclude that the impact of Blockchain on the MRO business model is considered positive. It is assumed that the average impact is considered positive if it exceeds a threshold of 3,5 (**Figure 23**). The logic behind this assumption is that most average scores range between 3 and 4, with 3 valued as a neutral and 4 as a positive impact. A decision was made to evaluate the impact as positive when it passes the average of the two values. Critical reviewers could lower the threshold.

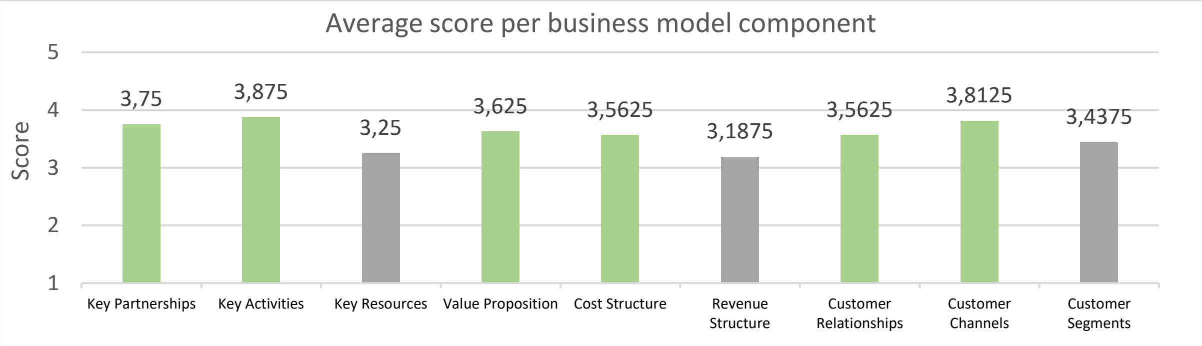

Figure 23 – Quantitative overview: impact of Blockchain on the MRO business model

The figure above can be translated into the MRO Business Model Canvas, which is a different way of presenting the quantitative results (**Figure 24**).

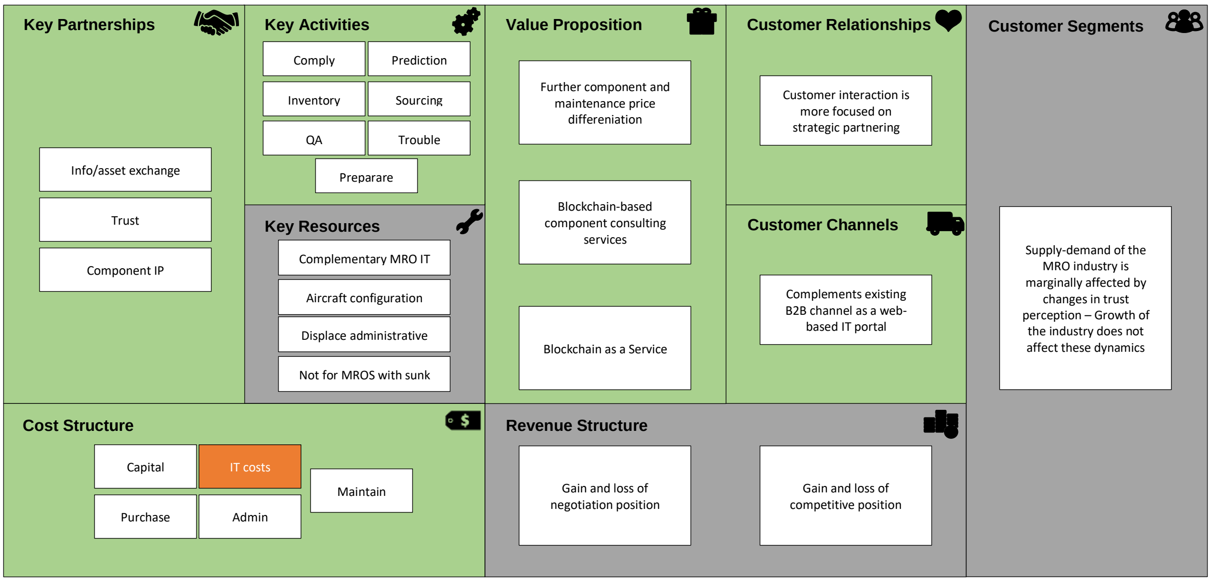

Figure 24 – MRO Business Model Canvas: Blockchain impact

Unfortunately, the quantitative results do not provide sufficient insight on why and how Blockchain could have a certain impact on MRO business model components. A table of all strategic impact areas are included, together with supporting and counter argument behind Blockchain (**Table 27**). In this table, 1) aircraft spare parts are shortened to parts; 2) next to the business model the quantitative result is shown (**see figure 24**).

Table 27 – Qualitative overview: impact of Blockchain on the MRO business model

Strategic impact area	Supporting argument	Counter argument
3.8 Key partnerships		
A1: Information and asset exchange	Standardise data exchange Reduce exchange at outsource Synchronise part data Real-time part data Confidence in part data	Leakage weakens partnerships Holistic view cause some to lose Parties might not want to share
A2: Supply chain and ecosystem trust	Trust in other parties Trust in part legitimacy Trust in part dataset	Trust is needed for Blockchain Trust in MROs already expected Trust in data integrity required
A3: Component IP control	Increase access to OEM IP	OEMs incentivised to control
3.9 Key activities		
B1: Regulatory compliance	Acquire part data faster	Parties may not share the data
B2: Predictive maintenance	Draw on global reliability data	Blockchain scalability
B3: Inventory management	Global view on part availability	Requires predictive maintenance
B4: Component sourcing	Flexible sourcing strategies	
B5: Quality assurance	Reduce paperwork	Storage problem
B6: Maintenance troubleshooting	Reduce part replacement	
B7: Maintenance execution	Improve preparation	No impact on core maintenance
3.3 Key resources		
C1: Physical resources	Blockchain complements IT Utilise smart contracts Still work with paperwork	Challenge to integrate with IT Immutability problem Regulatory opposition
C2: Intellectual resources	Aircraft configuration control Reduced counterfeit parts Improved part intelligence	Data consistency is difficult Requires widespread support Commoditised part analytics
C3: Human resources	Reduce administration	Back-office employee resistance Invest in IT/Business experts
C4: Financial resources	Large MROs can support effort Small MROs in a better position	Large MROs face sunk costs Difficult business case
3.6 Value proposition		
D1: MRO core value proposition	Improve price differentiation	Core proposition not affected
D2: Ecosystem-based analysis	Consultancy to authorities Consultancy to operators	OEMs monetise data feeds Easily commoditised
D3: Blockchain as a Service	Subscription revenues	Requires widespread support Conflicts Blockchain philosophy
3.6 Cost structure		
E1: Inventory costs	Through optimised inventory	Parties may not share the data Required predictive maintenance Blockchain scalability
E2: Part purchase costs	Through improved sourcing	
E3: IT costs		Short-term IT transition Long-term IT support Unknown Blockchain cost model
E4: Administrative costs	Through reduced labour Through reduced interactions Through reliable tracking	
E5: Maintenance costs	Through improved part data	Applicable in only few situations
3.2 Revenue structure		
F1: Negotiation position	Same: operator in emergency Gain: leverage around OEMs	Loss: real-price transparency Loss: part cycle transparency Loss: use of shared data
F2: Competitive position	Gain: ecosystem-based analysis Gain: if adopted by few Same: if adopted by industry	Loss: forced to switch Loss: exposure to smaller MROs
3.6 Customer relationships		
G1: Customer interactions	Less bargaining and disputes Reduce operator frustration	Nature of relationships same Impact is questionable
3.8 Customer channels		
H1: Blockchain portal	Distribute part data to operator Act as a robust B2B channel	Unlikely to replace channels
3.4 Customer segments		
I1: Supply and demand dynamics	Open up to a larger market Gain clients looking for trust	Industry already faces growth Trust perception is marginal

6.1.4 Robustness of the MRO business model

The second part of the results focused on the robustness of the MRO business model when it is confronted against the main stress factors identified in chapter 3: degree of data exposure; degree of network support; degree of regulatory support. After addressing the third research question, a workshop session occurred with an independent MRO. These results were acquired by reviewing audio files and post-it notes. By constructing a heat map and engaging in a sub-view and pattern analysis, the results provide answer to the fourth research question:

How robust are MRO business models when it is confronted against Blockchain as an aircraft spare part track and trace capability?

Through a Business Model Stress Test workshop, the MRO Business Model Heat Map has been completed (**Table 29**).

Table 29 – MRO Business Model Heat Map

	Scenario	Blockchain as an aircraft spare part track and trace capability					
	Stress factors	Data exposure		Network support		Regulatory support	
	Outcomes	Limited	Sensitive	Limited	Industry	Limited	Support
Business model components	Key Partnerships	1A	1B	1C	1D	1E	1F
	Key Activities	2A	2B	2C	2D	2E	2F
	Key Resources	3A	3B	3C	3D	3E	3F
	Value Proposition	4A	4B	4C	4D	4E	4F
	Cost Structure	5A	5B	5C	5D	5E	5F
	Revenue Structure	6A	6B	6C	6D	6E	6F
	Customer Relationships	7A	7B	7C	7D	7E	7F
	Customer Channels	8A	8B	8C	8D	8E	8F
	Customer Segments	9A	9B	9C	9D	9E	9F

A sub-view analysis on the rows of the heat map shows that the MRO business model is considered robust, since 1) two components are robust in all scenarios (key activities, customer channels); 2) five components are not robust in one out of six scenarios (key partnerships, key resources, value proposition, customer relationships, customer segments); 3) only two components are not robust in two out of six scenarios (cost structure, revenue structure). This shows that the MRO faces a trade-off between its key maintenance activities and its cost and revenue structures. A sub-view analysis on the columns of the heat map shows that the MRO business model cannot be pressured by Blockchain alone, but rather by the premise of extensive data exchange. Additionally, given the importance of the network effect and regulatory nature of the MRO industry, MROs can only perceive noticeable improvements to their business model when the industry and institutions supports Blockchain.

A pattern analysis of the heat map show that MROs should opt for a regulatory-backed Blockchain solution where only traceability and logbook data are exchanged throughout the entire industry. Additionally, the pattern analysis show that four business model components are consistently impacted in all outcomes of data exposure (key activities, cost structure, customer relationships, customer channels) and two business model components in all outcomes of regulatory support (revenue structure and customer relationships). Finally, by evaluating the best-case scenario, where limited data is shared through Blockchain with industry and regulatory support, three business model components are identified that are internally inconsistent throughout the scenarios (value proposition, revenue structure and customer relationships).

6.1.5 Feasibility of the Aviation Blockchain consortium

The third part of the results focused on the feasibility of the Aviation Blockchain consortium, since this is considered important by interviewees. These results represent additional themes that follow the interview coding procedure. Throughout the interviews, the participants consistently took the initiative to raise three main concerns regarding the establishment of a Blockchain consortium: the problem of data ownership; the need to incentivise parties; opposition from authorities. By discussing these additional results, it is possible to address the fifth and final research question:

How feasible is it for the aviation industry to consider a Blockchain consortium for the purpose of aircraft spare part management?

An overview is provided to show the main concerns that oppose Blockchain feasibility and how it is manifested through different problems (**Table 30**).

Table 30 – Aviation Blockchain consortium feasibility evaluation

Feasibility factor	Concern	Problem
Problem of data ownership	Blockchain ownership Blockchain initiation	Parties claim ownership Parties present opportunism
Need to incentivise parties	Opposition from OEMs Opposition from Operators	Change in industry dynamics
Opposition from institutions	Opposition from EASA/FAA	Concern about data protocol

The feasibility of the Blockchain consortium depends on whether the aviation industry can address the three main feasibility factors. Unfortunately, the establishment of a Blockchain consortium faces different problems that make it difficult to address the problem. The first problem is that industry participants already claim ownership over component data, which will not necessarily be solved with Blockchain since interaction and exchange between and among industry participants (e.g. MRO/OEM/operator) and institutions (e.g. IATA/EASA/FAA) are limited and political in nature. The second problem is that industry participants possess an opportunistic nature: if Blockchain initiation and ownership is allocated to a specific party (e.g. OEM), they can exclude opposite parties (e.g. competitors) from entering the Blockchain. The third problem is that industry participants are incentivised to not enter the Blockchain consortium, since they might lose negotiation and competitive position; lose component IP control; or may not be willing to open up their component data on Blockchain. The fourth problem is that a Blockchain solution, where no party owns the data, will simply not be accepted by regulators that are concerned about data responsibility, location and ownership.

These problems are evident examples of the fragmented nature of the aviation industry, which might make it difficult to establish a Blockchain consortium. In order for the Blockchain consortium to be considered a feasible consideration, key industry parties must determine which component data is shared on the Blockchain and who would own that respective data segment. This shows that the initiation and ownership of the Blockchain should be distributed between industry participants and regulatory institutions in order to prevent opportunism in this stage. However, since a solution in which no party owns the data may not get accepted by regulators, it may be necessary to exclude authorities from the early stage of Blockchain adoption. It is necessary that Blockchain must first emerge as an industry standard, propelled and initiated by key industry participants and IATA. In a later stage, the EASA or FAA may be involved in order to maintain oversight over the Blockchain ecosystem and assure that all participants have the right capabilities to not pollute the ecosystem. However, until authorities are convinced that they can use Blockchain to remotely monitor and audit components, they will continue to emphasise paper records and signatures.

6.2 DISCUSSION

This paragraph provides critical discussion on the main research problem (6.2.1), research objective (6.2.2) and Blockchain limitations (6.2.3).

6.2.1 Research problem: Lack of transparency in the aviation supply chain and ecosystem

This paragraph is dedicated to address the research problem:

Due to the complexity of aircraft spare part management, the aviation supply chain is not deemed as transparent as desired

Once the technical, functional and industry challenges have been addressed, it is possible to adopt Blockchain as an inter-organisational digital distributed component logbook. All participants would have increased control over their aircraft configuration, since they would be able to track and trace every change in the movement, ownership and condition of aircraft spare parts. This would increase the transparency of the supply chain and ecosystem, since component data is made immediately available in the data sharing processes. This is evident since both EASA and FAA can be involved in the Blockchain consortium and have real-time access to the data of hashed components. The ecosystem can improve their component coordination capabilities and reduce the risk of counterfeit spare parts from entering the supply chain. In the aviation industry this premise is made possible by the disruptive capability of Blockchain to disintermediate aircraft component brokers who often distribute most of the counterfeit components throughout the market. This disintermediation is made possible since Blockchain would replace these brokers as an exchange platform and remove illegitimate brokers as an intelligence platform. In the end, the aviation industry would acquire more transparency and trust in the validity of aircraft spare parts and its data due to access to immutable component data and reduction of counterfeit aircraft spare parts.

6.2.2 Research objective: Robustness of MRO business models in Blockchain consortiums

This paragraph is dedicated to address the research objective:

Evaluate the robustness of MRO business models when a Blockchain consortium is established for aircraft spare part management

Blockchain as an aircraft spare part track and trace capability is not only strategically relevant for cost-conscious innovating MROs, it also does not impose a risk to the robustness of their business model in most scenarios. Blockchain complements RFID, IoT and existing MRO IT to solve the limitations of information synchronisation, data access and security. It would act as the architecture that allow MROs to meet their regulatory requirements and improve their maintenance activities. This would support the cooperation and trust between MROs, OEMs and operators through improved exchange activities and IP access. MROs would be able to differentiate themselves through Blockchain-based services and through calculated risk. Even though Blockchain could be seen as a web-based portal that can improve the interaction between an MRO and operators, they could lose their negotiation and competitive position. Through Business Model Stress Test, it was made clear that most business model components are robust in most scenarios. MROs should opt for a regulatory-backed Blockchain consortium where only traceability and logbook data are exchanged throughout the industry. If sensitive data is exchanged, this would threaten the MRO business model and incentivise them to not participate in the Blockchain consortium. This is one of the reasons why participants doubt whether component data will actually be shared, especially since it threatens the feasibility of the consortium. This shows that it is necessary to consider the robustness of the MRO business model in scenarios where a Blockchain consortium seems feasible. Unfortunately, due to the problem of data ownership, the need to incentivise parties and opposition from regulatory institutions, it might be a challenge to establish a Blockchain consortium.

6.2.3 Blockchain limitations: Critical reflection for aircraft spare part management

Literature identified various Blockchain risks and limitations that raises the question whether it is desirable to adopt the technology within the aviation industry. Specific attention is given to the limitations that are identified throughout the interviews: 1) scalability; 2) privacy; 3) immutability; 4) storage; 5) government regulation; 6) business model alignment. Interviewees did not raise concerns surrounding the consensus mechanisms, nor did they mention or perceive the threat of quantum computing.

Scalability: Technical factor opposing extensive data exchange

Through literature, it was made clear that limited scalability becomes a major issue when components are extensively exchanged between aviation industry participants. Interviewees share this perspective, since predictive maintenance is only possible when the Blockchain can be scaled to a degree that supports component reliability data presentation. This is unrealistic, since it would impose enormous and unwarranted storage costs to MROs and other industry participants. Not only is it desirable to share limited data to protect the MRO business model, it further limits potential problems associated with Blockchain scalability. Unfortunately, it is currently unknown how often aircraft spare parts are exchanged between industry participants and how often these changes must be recorded. Therefore, it is difficult to make a claim on whether the Blockchain scalability problem imposes an issue for spare part exchange activities.

Privacy: Risk for industry negotiation and competitive dynamics

Privacy is typically a problem for public Blockchains (e.g. Bitcoin), where transactions could potentially expose identities of individuals. For the aviation industry, the problem of privacy is manifested in ways that could affect the negotiation and competitive dynamics between key industry players. A typical example is that MRO key partnerships could deteriorate if the Blockchain could provide competitors with component transaction or historical maintenance data. Normally, parties have only limited access to this data, which is why it is understandable why participants believe that MROs could lose their negotiation position vis-à-vis OEMs and operators. This is a natural response, since the aviation industry is characterised by its secretive and fragmented nature. At the same time, the increased transparency could impose competitive risk to the MRO industry, as opportunistic competitors (e.g. OEM) could oppose a smaller MRO from entering the Blockchain. Even though this could be beneficial for operators, it is a real question whether MROs would accept this risk.

Immutability: Conflict between Blockchain and aircraft maintenance philosophies

Currently, trivial component data must be manually shared between OEM, MROs and operators, which already is subject to human error. It is only possible to eliminate human error through Blockchain if this is used in conjunction with other technologies, such as RFID and IoT. And even so, if human error somehow ends up on the Blockchain, the consortium will face the problem of Garbage-In, Garbage-Out. Due to Blockchain's immutability property, invalid data that ends up on the Blockchain as a result of human error or a technical error from faulty RFID tags could not be corrected. This is an important issue in the aviation industry, where every action is subject to multiple checks to eradicate potential mistakes. What this exemplifies is the conflict between two philosophies: the Blockchain philosophy to provide access to immutable data; the aviation maintenance philosophy to prioritise aircraft airworthiness and safety. Blockchain can only improve aircraft airworthiness procedures under the assumption that no garbage data ends up on the Blockchain and that industry participants should be able to correct any potential garbage data. This philosophical conflict is a major reason why critics question Blockchain emergence in the regulated aviation industry. Unfortunately, interviewees were not able to provide solutions for this problem. However, suggestions were given to start Blockchain small and ensure that spare part management could work for non-critical flight components. Authorities were suggested to be involved early, primarily to ensure that all parties agree with the data policy and smart contract structures. An alternative is an editable Blockchain solution, which currently is being developed by technology consultancy architects.

Storage constraints: Problems of storage extend beyond capacity

The problem of data storage is normally related with disproportional costs when an enormous of data must be stored on the Blockchain. These costs would only increase if trivial component data is shared on the Blockchain, which is why industry participants and institutions must together determine which data ends up on the Blockchain. However, even if the problem of data capacity is solved, there are political problems that are inherent to the aviation industry that cannot easily be solved with Blockchain. An important consideration is that data storage is already a critical issue, primarily manifested through physical location and distribution. This problem can be perceived from two different lenses: the industry participant and industry institution perspectives. From the industry participant perspective, changes in data distribution would be a risk for the industry negotiation and competitive dynamics. From the industry institution perspective, physical data location and distribution becomes a major controversy when geographic locations are in conflict. In these circumstances, the federal government could mandate their national aviation authorities to acquire data on foreign aircraft. This example shows that data is already an important issue in the aviation industry, which will definitely not be solved with Blockchain where data is synchronised and stored on distributed databases throughout the world. This, again, conflicts against the secretive and fragmented nature of the aviation industry, which Blockchain is trying to distort with its philosophy. However, it is questionable to what extent this problem would truly oppose the aviation industry from adopting Blockchain for specifically aircraft spare part management.

Government regulation: Fragmented nature of aviation authorities

Without the support of the authorities, it is difficult to establish a Blockchain consortium that would be accepted as an industry standard. Not only is it possible to identify power political conflicts between industry participants, it is also possible to identify this between industry institutions. Industry participants typically underestimate the opposition from industry institutions regarding new technologies, especially in the aviation industry where safety is a priority. The difficulty to introduce innovation to authorities (e.g. EASA and FAA) is the main reason why IATA might conflict with the authorities. It shows that industry institutions are as fragmented as industry participants. The problem is that there are many regulators with their own vision over how Blockchain should be established and designed. EASA and FAA are very fragmented, since they are driven by different decisions (e.g. US congress/EU commission respectively). The regulatory nature of the aviation industry, where industry participants are expected to emphasise scrutiny in its processes for the purpose of safety, actually underscores the need of these participants to consider Blockchain. Therefore, industry institutions must be convinced that Blockchain's philosophy could be aligned with aircraft maintenance philosophy and yield safety benefits.

Business Model alignment: Critical condition for track and trace performance

This research first framed changes in the aviation ecosystem as a result of Blockchain adoption for aircraft spare part management. Based on this, the remainder of the research evaluated how these changes affect the MRO business model. Throughout the research, incentives were identified that position MROs, OEMs and operators to oppose Blockchain. Examples include changes in negotiation and competitive dynamics, component IP access and financial incentives. The problem is that network support is required in order to derive value from Blockchain: when industry players do not participate with Blockchain, component track and trace capabilities deteriorate when components are exchanged with parties that are not part of the consortium. This is one primary factor that could undermine the entire purpose of Blockchain as an aircraft spare part track and trace capability. To ensure optimal component track and trace performance, it is critical to involve as much industry participants as possible. Therefore, industry participants must be convinced that Blockchain can be aligned with their business models and yield business benefits.

6.3 RECOMMENDATIONS

This paragraph is dedicated to provide two sets of recommendations: management recommendations that help MROs prepare for Blockchain (**6.3.1**); academic recommendations that discuss opportunities for future research (**6.3.2**).

6.3.1 Management recommendations: preparing MROs for Blockchain

Blockchain adoption is a complicated matter that could yield opportunities, as made evident throughout this research. This section is dedicated to MROs that are interested in Blockchain and wish to be appropriately prepared for its adoption. The following recommendations are formulated: 1) design of the Blockchain solution; 2) maturation of the Blockchain solution; 3) establishment of the Blockchain consortium; 4) support of the Blockchain consortium; 5) position of MROs in the Blockchain consortium; 6) improving robustness of the MRO business model.

Design of the Blockchain solution

The Blockchain must work in cooperation with RFID, IoT and existing MRO IT systems. MROs, OEMs and operators should adopt distributed ledger databases and develop a private permissioned Blockchain network where only permissioned participants can read, edit and validate. It is recommended to adopt the Practical Byzantine Fault Tolerance consensus mechanism, since it allows high-throughput transactions without the necessity of opening up the ecosystem to larger groups. Since this can be a complicated endeavour, it is recommended to start with a small Blockchain Proof of Concept that hashes one RFID and IoT enabled rotable aircraft spare part or engine limited life part.

Maturation of the Blockchain solution

To mature the system, it is necessary to 1) develop technical frameworks and applications that allow end-user interaction through a web portal; 2) align and integrate the Proof of Concept with MRO IT systems (e.g. ERP); 3) experiment with data synchronisation between supply chain participants through Blockchain; 4) ensure that the solution does not interfere with aircraft equipment and meet airworthiness criteria; 5) ensure that the solution complies with Spec 2000 recommendations. Once the system matures, it is possible to start hashing other components.

Establishment of the Blockchain consortium

The initiation and ownership of the Blockchain should be distributed between industry participants and regulatory institutions in order to prevent opportunism. This consortium should only involve MROs, OEMs, operators, other key industry participants (e.g. repair shops) and institutions (e.g. EASA, FAA, IATA). It is important to try to involve the authorities early in this establishment, who could mandate component data entry. Otherwise, key industry participants should propel the consortium together with IATA. In a late stage, the EASA or FAA may be involved to maintain oversight over the Blockchain ecosystem and ensure all participants have the necessary capabilities.

Support of the Blockchain consortium

Since the Blockchain consortium is only feasible when the network effect is present, it is necessary to convince MROs, OEMs and operators to participate in the consortium. This research was focused on providing incentives for MROs to consider adoption, whereas subsequent research should develop incentives for OEMs and operators by evaluating the robustness of their business models. Until then, it is possible to strengthen awareness and interest among these parties by convincing authorities that it is desirable to use Blockchain to remotely manage, monitor and audit components.

Position of MROs in the Blockchain consortium

Even though Blockchain as an aircraft spare part capability does not affect the robustness of the MRO business model in most scenarios, MROs can acquire a certain position in the Blockchain consortium. MROs should make it very explicit that component reliability data should not end up in the Blockchain, since it could pressure their business model and incentivise them to not participate in the consortium. From an MRO perspective, it is considered ideal to engage in a regulatory-backed Blockchain consortium through which they share limited component data throughout the entire industry.

Improving robustness of the MRO business model

In the scenario that MROs perceive the risks of Blockchain, for example when regulatory institutions require them to expose their data, they face different options to deal with this risk. They could retreat from the Blockchain consortium under the notion that their business model is threatened. Alternatively, they could proactively seek new cost and revenue models that can be leveraged through Blockchain by acquiring efficiencies in component maintenance administration or by engaging in ecosystem-based component analytics to provide consultancy services to regulators and operators.

6.3.2 Academic recommendations: considering future research

This research introduced the opportunity for future research in the field of aircraft spare part management, Blockchain technology and business models. However, these opportunities can be expressed on different levels: 1) strategic; 2) replication; 3) operational.

Research on strategic level

It is possible to execute this research in different industries, with different applications and other participants:

- Identify how the Blockchain track and trace capability (e.g. car components) can impact business models (e.g. car manufacturer) in different industries (e.g. car industry).
- Identify other Blockchain MRO use cases beyond aircraft spare part track and trace (e.g. MRO employee authorisation) and identify its impact on the MRO business model.
- Identify how OEMs, aircraft operators and regulators can be convinced to consider Blockchain as an aircraft spare part track and trace capability;
- Identify how component brokers, who experience Blockchain disintermediation, can engage in Business Model Innovation in order to remain relevant in the industry.

Research on replication level

It is possible to replicate this research in order to verify or falsify the main findings:

- Replicate the findings of this research by conducting interviews with a larger sample size and different industry participants;
- Replicate the findings of this research by adopting different research methodologies and different business modelling methods;
- Replicate the findings with further consideration of Blockchain scalability and number of component transactions throughout the aviation industry.

Research on operational level

It is possible to execute this research when Blockchain is entering widespread adoption:

- Identify how exactly the MRO strategic implications translate to operational implications once Blockchain is adopted (e.g. business process management);
- Identify how the Blockchain architecture should be designed and integrated with existing MRO IT architecture for this specific use case;
- Identify how exactly a Blockchain consortium could affect the power position of MROs, OEMs and operators.

7 REFLECTION

The seventh and final chapter of this thesis reflects upon the strengths and limitations of the research (**7.1**); the managerial (**7.2**) and academic relevance of the research (**7.3**); the relationship of this research with Management of Technology (**7.4**).

7.1 STRENGTHS AND LIMITATIONS OF THE RESEARCH

Throughout chapter 3 and chapter 4, strengths and limitations of each research design decision were discussed. This paragraph, however, recognises and evaluates the quality of the research in its entirety by reflecting upon its strengths (**7.1.1**) and limitations (**7.1.2**).

7.1.1 Research strengths

The first main strength of this research is that it builds upon literature on Blockchain technology and aircraft spare part management in order to construct a hypothetical business scenario. In this case, a Blockchain business opportunity was formulated upfront through a desk research, which allowed the interviews to focus on the evaluation of this opportunity rather than to try to identify new opportunities.

The second main strength of this research is that it builds upon literature on business models in order to provide guidance to the semi-structured interviews by adopting the Business Model Stress Test technique and the Business Model Canvas. In this case, the MRO business model was formulated upfront through a desk research and evaluated with Accenture employees, which allowed the interviews to focus on an impact assessment on predefined business model component variables rather than on business model contextualisation. Additionally, this circumvented the qualitative limitations of the Business Model Stress Test technique, where the validity and reliability of the research depends on the knowledgeability of interviewees.

The third main strength of this research is that it builds upon the theoretical and conceptual model in order to construct a research protocol. The purpose of this protocol is to improve research validity and reliability by mitigating the lack of rigor, generalisation, replicability and potential bias. Construct validity is safeguarded by incorporating multiple sources of evidences from both the consulting and aviation industry perspective. Internal validity was met by constructing a protocol that builds upon the theoretical and conceptual model. Even though only 16 expert participants were interviewed, an attempt was made to improve the external validity of the results by adopting quantitative assumptions. Reliability of this research was safeguarded by operationalising the research strategy and by including transcriptions as raw data in this report, which can be evaluated by critical readers.

The fourth main strength of this research is that it converges the final results in a triangulating fashion. This research adopts 1) different perspectives: consulting and industry; 2) different participants: two consultancies, two MROs and an OEM; 3) different expertise: Blockchain, MRO, MRO and Blockchain, supply chain, etc.; 4) different data: qualitative and quantitative; 5) different data collection methods: interview, focus-group discussion and stress test workshop. This complies with the nature of concurrent nested mixed methods research design.

7.1.2 Research limitations

The first main limitation of this research relates to its explorative nature, since Blockchain is in the early stages of adoption. Since Blockchain is currently not implemented or is in the very early stages of implementation, it is difficult to fully understand how well Blockchain could impact the underlying business model components. This evaluation is based upon the experience and knowledge of consultants and industry experts. Therefore, it is necessary to reflect upon the findings of this research once parties actually use Blockchain for spare part management.

The second main limitation of this research relates to limited qualitative data of the fourth interview from MRO 1. Due to technical problems, only the remaining 10 minutes of the discussion was recorded and transcribed. Unfortunately, the interviewee had limited time, so the entire meeting was cut short to 30 minutes, which resulted in a rushed interview. Normally, the interview ends with a quantitative evaluation that supports the qualitative discussion. This time it was the opposite, which limited the amount of qualitative knowledge that was shared and discussed. Additionally, it was possible to only interview two participants from MRO 2 and OEM. As a result, even though both consulting and industry are equally represented, MRO 1, MRO 2 and OEM may be individually under-represented in the final results of this research.

The third main limitation of this research relates to the survey, which was designed with time restrictions in mind. Since these surveys were distributed at the end of each interview, it was not possible to acquire extensive quantitative data on user perception. Providing an extensive survey at the end of the interview would complicate the data collection process, since industry participants would be less incentivised to participate. Therefore, a conscious decision was made to only provide a short survey at the end of the discussion to quantitatively capture the perspective of participants. Had the research and interviews not faced time restrictions, it would be possible to develop and distribute a sophisticated survey. Furthermore, it can be questioned to what extent survey results from 16 interviewees can truly be generalised.

The fourth main limitation of this research relates to bias, since intersubjectivity is introduced through the data. One reason is that the research is mostly limited to participants that are connected with Accenture's network, which could cause bias towards Blockchain promotion. However, an attempt was made to solve this by interviewing different industry participants throughout the supply chain (e.g. independent MROs/airline-owned MRO/OEM). Even with varying industry perspectives, all parties demonstrated comparable insights and opinions.

The fifth main limitation of this research relates to the usage of the Business Model Canvas, which currently is limited to correctly capture the interactions of an MRO in the wider aviation ecosystem. In this ecosystem, partners and clients are typically intertwined, which complicated the discussion with industry participants. The Business Model Canvas provides a black-and-white perspective on the partners and customers of an MRO, while in reality these customers often are also considered MRO partners. The Business Model Canvas was also incapable of fully relating the political discussion of the establishment of a Blockchain consortium to any specific business model component.

The sixth main limitation of this research relates to the usage of the Business Model Stress Test, technique which typically does not include quantitative assumptions to support the qualitative results. It is questionable whether the quantitative assumption of this research is considered sufficient in rectifying this limitation. Furthermore, it is difficult to objectively evaluate the quality of input from interview participants, since no performance criteria are formulated that allow researchers to evaluate it. Finally, since the method only considers the impact of an event and not its likelihood, any statements regarding the likelihood of a scenario is not completely unbiased.

The seventh main limitation of this research relates to the literature review, where the process of selecting and acquiring sources were poorly documented due to the explorative nature of this research. The literature review is still included, with the list of literature, its general insight and contribution of this research (**Appendix XVIII**).

The eight and final main limitation of this research relates to Blockchain limitations, which in the end was incorporated and critically discussed. However, had the research design appropriately integrated Blockchain limitations, it would have been possible to discuss the Blockchain scalability problem within the aviation industry in more detail.

7.2 MANAGERIAL RELEVANCE OF THE RESEARCH

The emergence of Blockchain is considered one of the largest technological trends faced by the MRO industry. With the importance to properly coordinate component maintenance for the goal of assuring aircraft airworthiness, MROs try to adapt and prepare their landscape for any technological disruption. Currently, MROs, OEMs and operators are evaluating the potential of Blockchain and try to identify potential use cases. Since there is clear evidence of interest in the technology, it is necessary to guide the participants throughout the adoption process.

First, this research provides insight in changes in component information presentation, ecosystem and exchange processes. Maintenance managers are confronted with component data in order to evaluate the ability to install it on an aircraft. However, since back-to-birth records are not always present, this research shows how these managers could access this information in a web-based portal. The importance relates to the quality of that information, which at that moment is shared and synchronised instantly between ecosystem participants. Thus, changes in the ecosystem provide these parties with the opportunity to reconsider the infrastructure that provides foundation to maintenance coordination.

Second, this research not only captures the MRO landscape, but also documents how this landscape can be captured. This is a recognised problem by both consulting and industry participants, since extensive experience is required to enter and understand the complex MRO landscape. This research guides any prospective manager throughout its landscape by capturing it in a refined Business Model Canvas. This research also provides introduction of Business Model Stress Test for the aviation industry, which allow executives to structurally evaluate the robustness of their business and maintenance strategies.

Third, this research helps both MROs, OEMs and operators understand how Blockchain can affect an MRO's partnership and customer interactions, maintenance activities, resources, cost structure, negotiation and competitive position. This is relevant when the industry is ready for a Blockchain consortium, since these incentives and challenges can be introduced in that discussion. Since this research actually focused on a specific use case, these entities can redirect their focus from speculating use cases to discussing strategic impact.

Fourth, this research considers the strategic impact of Blockchain in order to evaluate the robustness of the MRO business model. Based on this evaluation, recommendations are formulated that help these MROs to strengthen or reposition themselves in an environment characterised by Blockchain-based aircraft spare part management.

Fifth, this research introduces a coordinated approach to the establishment of the Blockchain consortium. The regulatory and fragmented nature of the aviation industry complicates any real coordinated effort in managing an industry-wide consortium, which shows why this research can help these parties to focus on the initiation, ownership and incentives for all parties to participate in the consortium. The overview of scenario assessment could give guidance to why these parties must share this initiative.

Sixth, this research aims to inspire aviation industry participants to change their conservative paradigm regarding technology and innovation by providing a multi-actor perspective towards Blockchain. The regulatory nature of the industry should not discourage managers from considering the impact of these new technologies, since competitors may try to leverage it in order to component aircraft maintenance coordination. Even when restricted by regulation, industry participants should seek cooperation with regulatory authorities in order to align their business incentives with the objective of aircraft safety.

7.3 ACADEMIC RELEVANCE OF THE RESEARCH

This paragraph describes the academic relevance of the research, since the research draws upon literature in order to address the research objective. Without a clear academic contribution, it is difficult to position this research within broader literature. However, there is clear contribution to literature in the field of aircraft spare part management (7.3.1), Blockchain technology (7.3.2) and business models (7.3.3). A literature review is provided in the appendix that highlights all literature, its general insight and the research contribution to each individual source (Appendix XVIII). In this appendix, references are made to the pages in the thesis that contains the content to support the underlying claim.

7.3.1 Contribution to literature on aircraft spare part management

Concerning literature on aircraft maintenance, this research represents the first initiative to illustrate how Blockchain and smart contracts can contribute to improving airworthiness procedures through increased supply chain and ecosystem transparency. Since predictive maintenance is an important maintenance strategy, this research also discusses the possibility that Blockchain can enable MROs to refine their predictive maintenance models. Furthermore, this research illustrates how Blockchain can be seen as an aircraft spare part track and trace capability that can improve configuration management of high-value assets (e.g. rotables and limited life parts).

When it comes to inter-organisational information sharing, this research is one of the few attempts to illustrate how Blockchain-based component asset and information exchange can enable improved aircraft spare part supply chain transparency through reduced information asymmetry. This research verifies previous findings on the relationship between inter-organisational information practices and organisational performance by illustrating how Blockchain can improve the MRO maintenance and administrative capabilities when information sharing practices improve between MROs, OEMs and operators.

In addition, this research extends literature on supply chain and ecosystem by visually presenting changes in structure of the aviation ecosystem and changes in the component asset and information flows between an MRO and aircraft operator. Furthermore, this research artistically shows how Blockchain can impact the presentation, accessibility and quality of Spec 2000 component data through a shared real-time web-based platform.

Finally, this research supports the notion that Blockchain can only act as a partial solution for the problems and complexities faced by aircraft spare part management. It does so by illustrating why it is important to consider Blockchain as a complementary system that must be aligned with existing MRO IT (e.g. SAP) and why it cannot replace these maintenance systems. For these complex supply chains, this research supports the notion that it is necessary to combine Blockchain with RFID tags and IoT sensors in order to take advantage of real-time component traceability and reliability data.

7.3.2 Contribution to literature on Blockchain technology

This research extends literature on Blockchain by illustrating how its cryptographic properties and hashing capabilities can digitally identify tangible (e.g. spare parts) and intangible (e.g. certificate of airworthiness) assets. This contributes to research on Blockchain 3.0, where focus moves from cryptocurrency and finance (e.g. Bitcoin) to aircraft maintenance and spare part management. It does so by focusing on the specific Blockchain use case of supply chain management and extends this with the idea that Blockchain can be used as an aircraft spare part track and trace capability. Furthermore, this research supports and illustrates the notion that Blockchain remedies the problems associated with spare part provenance by reducing reliance on paper, reducing counterfeit assets and encouraging IT standardisation.

This research supports the notion that Blockchain can enable disintermediation and trust in any given industry, which is also applicable for the MRO industry. This is exemplified by how component transparency can impact the interaction between an MRO and its partners without any component brokers. By adopting a taxonomy, this research further validates the necessity to deploy a private permissioned Blockchain consortium for a conservative industry, such as the MRO industry. Additionally, by assuming that Blockchain must be used in combination with RFID and IoT to track and trace aircraft spare parts, it contributes to existing literature where the combination of these technologies is used in the food and diamond supply chain.

The research further contributes to literature on Blockchain governance by illustrating how each aviation industry participant assumes their role in a Blockchain consortium. The discussion on the initiation and ownership of the Aviation Blockchain consortium creates understanding of whether it is viable to consider shared ownership in a regulated industry. Finally, incentives are developed for MROs, OEMs and operators participate in the Blockchain consortium. Specifically, this research contributes to literature that raise the concern about the impact of Blockchain on existing business models.

7.3.3 Contribution to literature on business models

This research extends literature on business model by illustrating how Blockchain as an aircraft spare part track and trace capability could impact the MRO business model. Since the model is based upon previous literature, this research extends that literature by incorporating insights from consulting and industry practitioners to refine the MRO business model.

By adopting the Business Model Canvas model, this research proves its practical usability since it is considered an accessible framework by executives and managers from the aviation industry. However, this research contributes to literature on the Business Model Canvas by identifying two flaws that make it slightly incompatible with the findings of this research: 1) the model is limited in fully relating the dynamics of establishing a Blockchain consortium to a specific business model component; 2) the model provides a distorted reality of the MRO partners and customers, which in the model are separated, but is in reality intertwined.

Finally, by adopting the Business Model Stress Test technique, this research proves its ontology-agnostic nature by combining this technique with the Business Model Canvas specified on the MRO business model. This research contributes to the technique by adopting an unconventional approach that incorporates a quantitative assumption through a survey that is distributed at the end of each interview. By capturing the results on an itemised rating scale, it is possible to objectify the construction of the business model heat map.

7.4 Relationship with Management of Technology

This paragraph provides a relationship between the research and the Master of Science programme of Management of Technology, which is a discipline that evaluates technologies as a corporate resource. This research was shaped with the subjects that are part of core themes of the programme: Technology, Innovation and Organisation (**7.4.1**); Technology, Innovation and Commercialisation (**7.4.2**); Technology, Innovation and Engineering (**7.4.3**).

7.4.1 Technology, Innovation and Organisation

This research considers how MROs exchange component data and analyses the extent to which Blockchain-based information exchange could affect the MRO performance, which shows a relation to the course of Leadership and Technology Management (MOT1524). One important issue is aligning interest of management and employees, especially since Blockchain could affect the administrative back-office activities of an MRO provider. As it was made evident throughout the course and research: compared to larger incumbent organisations, small flexible MROs are less restrained in adopting Blockchain technology.

This research considers the relationship between Blockchain, the MRO information exchange process and maintenance strategy, which shows a relation to the course of Business Process Management and Technology (MOT1531). Typically, business process improvement initiatives necessitate the adoption of Lean, Six Sigma or Theory of Constraints. Even though this research does not focus on how the underlying MRO business processes can adapt or improve in Blockchain-based aircraft spare part management, this research highlights why Blockchain could enable MROs to evaluate their back-office processes.

This research considers the component decision-making dynamics between MROs, OEMs and operators in its multi-actor setting, which shows a relation to the course of Inter- and Intra-Organisation Decision Making (MOT1451). Even though these parties act to the best interest of aircraft safety and airworthiness, it is clear that the fragmented nature of the aviation industry typically cause these isolated parties to take sub-optimal decisions. This contributes the complexity of aircraft spare part management, where parties are subject to information asymmetry and component compatibility disputes. Throughout this research, Blockchain is considered as a technology that can affect these negotiation dynamics, since it can enable industry participants to analyse a global pool of aircraft spare parts and reduce these disputes.

7.4.2 Technology, Innovation and Commercialisation

This research considers the impact of Blockchain as a web-based communication platform on the relationship between MRO and their customers, which shows a relation to the course of High-Tech Marketing (MOT1532). It is important to note that this research is not focused on developing a Blockchain marketing plan. If anything, this research proved how it is less likely for MROs to promote Blockchain, since it will eventually be seen as a commoditised resource that is accessible by all aviation industry participants. Additionally, MROs will not promote Blockchain, since operators still consider other factors (e.g. hangar facilities, maintenance capacity) when selecting a trusted MRO provider.

This research considers the uncertainties that an MRO might face when it considers to use Blockchain for aircraft spare part management, which shows a relation to the course of Technology, Strategy and Entrepreneurship (MOT1435). This course shaped this research by considering the fundamental notion that firms exposed to uncertain environments focus on formulating and implementing technology strategies. This is made evident throughout this research, since it is uncertain to what extent parties would be willing to share component data on the Blockchain, and whether there would be support from other MROs, OEMs, operators, regulators (e.g. EASA and FAA) and standardisation institutions (e.g. IATA).

7.4.3 Technology, Innovation and Engineering

This research considers the drivers and barriers in the process of innovating and adopting Blockchain throughout the MRO industry, which shows a relation to the course of Technology Dynamics (MOT1412). The standardised MROs, OEMs and operators already use maintenance programs in order to assure airworthiness, which is why it was made evident that Blockchain could not replace these systems. Furthermore, the establishment of a Blockchain consortium, where some parties may win and lose, must be developed and employed responsibly in cooperation with the regulatory authorities and institutions.

This research considers the development and diffusion of Blockchain throughout the MRO industry, which shows a relation to the course of Emerging and Breakthrough Technologies (MOT2421). This connection was made evident when it was clear that the aviation industry is aware of the volatile nature of Blockchain and is currently evaluating the requirements to use the technology. Due to its shared nature, it is difficult to allocate initiation and ownership of Blockchain to one specific party (e.g. MRO, OEM or regulator). As it was made evident, if only one party engages with Blockchain, it is unlikely that the industry would accept the technology.

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