Governing the Blockchain

Establishing Governance Mechanisms for Long-term Data Sharing Blockchain Consortium in Aviation

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TU Delft

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by

Akal Devin Aras

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TU Delft

Executive Summary

The aviation industry is poised for substantial expansion, with forecasts predicting that passenger demand will double by the mid-2030s. This increase in demand presents both opportunities and challenges for various stakeholders within the industry. One sector anticipated to encounter difficulties is Maintenance, Repair, and Overhaul (MRO), particularly regarding data sharing within the supply chain for part tracking. Effective part tracking is essential as it entails crucial data that confirms the 'airworthiness' of parts, demonstrating their safety for operation. Currently, the absence of comprehensive inter-organizational maintenance record software impedes accurate tracking of aircraft parts. This lack leads to increased maintenance and communication costs for all stakeholders involved, as each party must independently verify parts history, often resulting in redundant work and additional pressure on profit margins.

With profit margins already under strain, aviation companies must innovate. One promising solution is blockchain technology, which has the potential to serve as an inter-organizational maintenance record system, facilitating the tracking and tracing of part histories and offering significant cost reductions. However, effective lifecycle tracking of parts requires a collective effort since multiple entities are involved at different stages of the lifecycle, making the formation of a data-sharing consortium necessary. The creation of such a consortium is further incentivized by the implementation of the Corporate Sustainability Reporting Directive (CSRD), which requires companies to disclose all activities related to both downstream and upstream value chains and assess their sustainability impacts.

Despite the potential for cost reduction, increased efficiency in inventory management, and legal mandates, companies remain hesitant to join a data-sharing blockchain consortium. Research into similar industry data-sharing consortia indicates that one persistent barrier to success is the design of governance mechanisms within the consortium. Although extensive research on governance mechanisms exists, stakeholder participation in these data-sharing blockchain consortia remains low.

The objective of this research is to develop governance mechanisms that enhance stakeholder participation by taking into account stakeholder values. To achieve this, a value-focused thinking methodology is utilized, ensuring that stakeholder values are integral to the governance design process rather than relying on arbitrary arrangements. In addition to conducting a literature review to discover values, contact was established with the Independent Data Consortium for Aviation (IDCA). IDCA is a global consortium of leading aviation companies at all levels of the industry coming together to develop the foundation for allowing data to be shared in a non-competitive manner. Its objective is to create a more efficient marketplace where both waste and the time required to get to a common solution are minimized. A combination of participatory observations within the part-tracking work group of IDCA and interviews with high-level executives from the aviation industry is conducted to discover stakeholder values. Three contexts, 21 values and 11 sub-values, were identified for joining a data-sharing blockchain consortium. The three contexts are the data that will be shared and received, the stakeholders that will join the consortium, and the blockchain platform that will be used.

Adopting such a broad perspective on values has necessitated the prioritization of these values to create a clear roadmap for the governance design process. This approach ensures that the final governance designs are not only comprehensive but also practical, enabling effective and sustainable blockchain implementation for part tracking in the aviation industry. To obtain this ranking, a survey employing the Bayesian Best-Worst Method (BWM) was used to systematically analyse stakeholder values where 12 aviation stakeholders pertaining to the eight different stakeholder groups encompassing the full life-cycle of a part were received.

Survey takers ranked the data context as the most important, underscoring the value companies place on data as their primary resource, which was followed by stakeholder context. On the other hand, the blockchain platform was ranked the lowest in importance, which was also justified by the credal ranking calculations indicating it is seen merely as a tool for data sharing. Within the data context, the values of integrity, access control, confidentiality, and ownership emerged not only as the highest priorities but also as the most important values overall. This underscores the critical importance stakeholders place on data. These were followed by the values of trust, legitimacy, neutrality, compliance, and benefit equality within the stakeholder context. Completing the top ten, security within the blockchain context was followed by adaptability and tangibility.

Once these stakeholder values are identified, governance designs can be proposed to ensure their fulfilment. A benchmarking study was conducted on existing governance research to understand its definition, scope, and blockchain data-sharing initiatives in other industries. The literature review revealed that no unified definition or established mechanisms for blockchain governance currently exist. Therefore, the researcher established the following definition:

"Consortium blockchain governance refers to the process and mechanisms that ensure the direction, control, and coordination of a blockchain platform to which stakeholders jointly contribute."

Given that consortium blockchain governance is a broad term, it is essential to keep its definition straightforward while supplementing it with specific mechanisms. To supplement this definition, a comprehensive table was developed that combines all previously identified mechanisms. **Table 5.2** enables stakeholders to easily access and select the governance mechanisms that align with the identified values. Finally, five real-world blockchain consortia were investigated to understand how these mechanisms are designed and implemented in projects that have undergone piloting or advanced further.

The research was finalized by linking the eight most important stakeholders' values to governance mechanisms and, subsequently, governance designs. One example is Executive neutrality, which concerns the impartiality of the entity controlling a platform's direction. Stakeholders also, during interviews, have stated from past experiences that the executive body might not remain unbiased, leading to decisions that favour specific parties. Several governance mechanisms can ensure executive neutrality, including legal compliance, where decisions are based on industry laws and standards. However, due to the underdevelopment of data-sharing policies, industry standards, policies cannot yet serve as reliable benchmarks. Another approach is relying on ethical responsibilities, assuming all participants will adhere to principles of the greater good, though this might be overly optimistic in a profit-driven ecosystem. Since this value primarily revolves around the decisions made by the governing body, decision rights are identified as the most suitable governance mechanism and governance designs can be established.

Based on similar projects like VeChainThor and PharmaLedger, four governance designs were considered: Ecosystem members-led, Service Provider-led, Foundation-led, Independently Governed, and Foundation-led Ecosystem Governed. It was decided, based on the stakeholder value, that the foundation-led ecosystem-governed model was the most suitable, where a non-profit foundation directs the network's operations while being accountable to a board comprising ecosystem stakeholders. This model ensures stakeholder involvement and collective decision-making, maintaining executive neutrality. Finally, it is acknowledged that design inherently involves trade-offs. Therefore, selecting a particular design to address one stakeholder's value can have ramifications on other values. Because of that, the design decision on other values is investigated. One potential downside is its impact on growth, as involving more stakeholders in decision-making can be challenging and may lead to resistance to adding new entities, potentially hindering growth. This method was employed for the other seven most important values that were identified through the BWM. However, it is important to note that this recommendation is based on the values identified through stakeholder interviews. If stakeholders prefer not to participate actively in the execution of governance duties, then a foundation-led, independently governed model would be more suitable. In this model, an independent non-profit entity would take on the responsibility of directing and managing the network, creating technology roadmaps, and providing necessary services, with limited direct involvement from the stakeholders.

In conclusion, to address the primary research objective of designing governance mechanisms that enhance participation in blockchain-based aviation part-tracking consortia, it can be stated that **there is no universally optimal governance mechanism design that enhances stakeholder participation; rather, this varies according to the values held by stakeholders within their specific context. As these values change depending on the context, it is recommended that decision-makers begin by investigating stakeholder values.** A value-focused thinking approach constitutes the primary contribution of this research, as it introduces a novel method of blockchain governance that prioritizes stakeholder values. By integrating these values into governance designs, a mutual understanding among consortium members is established, promoting more effective collaboration and decision-making. Furthermore, this research addresses a literature gap within the aviation industry, where blockchain consortiums have not been extensively examined.

For the initial phase of implementation, it is advisable to engage regulators to establish credibility, thereby fostering increased participation. Once a stable level of participation is achieved, the focus can then shift to examining the values of the stakeholders involved. Future research could assess the applicability of identified values and governance mechanisms in contexts beyond the aviation industry. Similar studies across various industries are important to ensure external validity. Additionally, further research could be conducted into how different mechanisms besides the one suggested in this research could fulfil stakeholder values and investigate the interaction among those mechanisms.

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1 Introduction

As per forecasts provided by the International Civil Aviation Organization (ICAO), it is predicted that by the mid-2030s, there will be a minimum of 200,000 flights per day worldwide. These projections suggest a doubling in passenger demand, which presents promising opportunities for the aviation industry. However, it should not come as a surprise that such an expansion inevitably poses significant challenges (ICAO, 2019). Beyond concerns regarding capacity loads, resource scarcity, and infrastructure limitations at airports, it is evident that such growth will inevitably trigger both physical challenges in goods transportation and digital complexities in data sharing within the supply chain. The aviation industry generates data on multiple fronts, including operational, supply chain, and passenger information. Some of this data contributes significantly to the overall safety of the industry and, therefore, needs to be shared. However, the sector, which already encompasses many stakeholders ranging from airlines to regulatory bodies, has consistently been challenged by the need to share precise data with its diverse array of stakeholders due to various complexities (J. Yadav et al., 2022).

1.1. Social Relevance

One of the primary challenges related to data sharing is that the lifespan of an aircraft can exceed 60 years, involving numerous stages and a wide range of stakeholders throughout its lifecycle. This leads to the generation of data at multiple points over an extended period, making it challenging to track and trace data regarding its parts while maintaining a sustainable data flow. A high-level overview of an aircraft lifecycle can be seen in **Figure 1.1**.

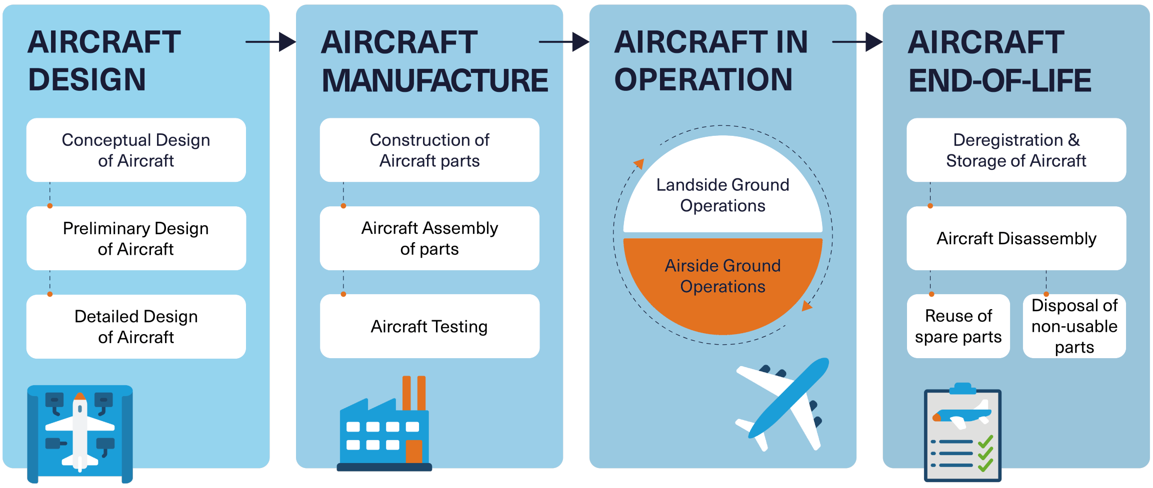


Figure 1.1: Aircraft Lifecycle Based on TU Delft Online Learning (2022)

One of the stages within the aircraft lifecycle is airside ground operations, which involve various tasks related to aircraft handling at airports, such as fueling, cleaning, and pushback. A crucial department within these operations is Maintenance, Repair, and Overhaul (MRO), which includes all tasks performed by the maintenance crew to keep the aircraft operational. These operations in the lifecycle are complex not only due to the long lifespan or aircraft configuration but also due to part management, supply chain and communication nature among stakeholders (Rajkov, 2018). Currently, the lack of efficient and comprehensive inter-organizational maintenance record software hinders the accurate tracking and tracing of aircraft parts. This lack of transparency leads to increased maintenance and communication costs for all stakeholders involved in the process, as each party must independently verify information regarding parts history and often perform duplicate work. (Sahay, 2012). Marx (2023) hypothesises that the implementation of an industry-wide data network providing comprehensive and trustworthy transparency to its stakeholders has the potential to result in annual operational savings of $30 billion for the commercial aviation sector. In line with this monetary saving, Ho et al. (2021a) states that multi-actor transparency could reduce 30% in parts inventory and carryover for MROs.

Simultaneously, airlines have consistently kept up with cutting-edge technology to create innovative solutions that increase their profitability and enhance their business offerings within the sector. This practice is characterized by tight financial operating margins driven by intense competition. An illustration of this innovativeness by airlines is the examination of blockchain technology, which is ”a distributed, immutable ledger that facilitates the process of recording transactions and tracking assets in a business network.” (IBM, 2024b, p.1).

This technological infrastructure has the potential to serve as inter-organizational maintenance record software that can help track and trace part history, offering significant cost reductions as previously highlighted. However, independent adoption by an airline or an MRO would be ineffective due to the multistage and multi-stakeholder nature of a part's lifecycle, similar to that of an aircraft. To efficiently track parts throughout their lifecycle in MRO operations, a coordinated effort among all stakeholders is essential.

A research initiative led by the Independent Data Consortium for Aviation (IDCA) represents a proactive step in overseeing aircraft components tracking from birth to disposal. IDCA describes itself as ”a global consortium of leading aviation companies at all levels of the industry coming together to develop the foundation for allowing data to be shared in a non-competitive manner. Its objective is to create a more efficient marketplace, where both waste and the time required to get to a common solution is minimized.” (Independent Data Consortium for Aviation, Independent Data Consortium for Aviation, 2021).

Additionally, the European Union (EU) is actively putting into practice the European Sustainability Reporting Standards (ESRS), which addresses Environmental, Social, and Governance (ESG) aspects of corporate sustainability (EuropeanUnion, 2020, 2022, 2023). This move aims to elevate sustainability reporting to a status equivalent to financial reporting within the EU. Starting from the 1st of January 2024, companies that have over 250 employees, more than 40 million € in annual revenue and more than 20€ million in total assets or balance sheets are mandated to disclose all activities connected to both downstream and upstream value chains and assess their implications on sustainability (Brightest, 2024). This directive forces airlines to have detailed knowledge of the carbon emissions produced during the part's production and maintenance phases. Consequently, it is anticipated that these directives will further incentivise companies to share comprehensive data regarding their supply chain processes, encompassing all associated maintenance activities.

Additionally, according to the studies of the International Air Transport Association (IATA), data sharing throughout the life cycle of an aircraft part greatly improves inventory control accuracy, reduces maintenance errors, and eventually enhances decision-making processes. Real-time tracking of each individual part, with a full history record, enables highly accurate inventory management because it gives real-time status visibility of parts and their location, hence reducing discrepancies and improving the forecasting of inventory needs(Ho et al., 2021b). This detailed information further serves to keep the maintenance record up-to-date and complete, therefore eliminating human error to a great extent and ensuring the regulations imposed by the manufacturers and other regulatory bodies concerning the servicing of equipment and vehicles. Having this real information, detailed and accurate, maintenance teams and inventory managers are able to make informed decisions on schedules of part replacement and maintenance, hence assuring optimization in inventory levels and avoiding extra costs. Finally, predictive maintenance, driven by data analytics, picks up potential issues before they escalate to improve operational efficiency and safety (Ho et al., 2021b).

1.2. Scientific Relevance

From a scientific perspective, multiple studies have been conducted regarding the benefits of blockchain implementation as an inter-organizational maintenance recording infrastructure in the aviation industry (Ahmad et al., 2021a; Efthymiou et al., 2022; Hughes et al., 2019). These studies extended beyond the benefits of blockchain to explore potential implementation methods, such as the Aydemir et al. (2020), Ho et al. (2021a), Madhwal and Panfilov (2017), and Schyga (2019) have successfully investigated the close monitoring of aircraft parts to establish the digital groundwork necessary for effective data sharing. Several pilot programs such as IBM Food Trust, MOBI, and TradeLens across various sectors have been conducted, yet the penetration levels of blockchain technology remain minimal (Maersk, 2022; MOBI, 2024; Trust, 2022). A more detailed explanation regarding the studies and pilot programs is explained in **subsection 2.4.1**

So, given the potential for significant financial benefits, the availability of a blockchain platform for data sharing, the creation of data sharing consortiums, and the EU's sustainability legislation, it is studied that a major obstacle to a successful blockchain consortium is the governance structure (Ávila et al., 2022; De Filippi & Loveluck, 2016; Gasser et al., 2015; Leewis et al., 2021; Liu et al., 2022; Niforos, 2018; Pelt et al., 2020; van Haaren-van Duijn et al., 2022).

1.3. Research Objective & Questions

Having recognized the potential benefits of data sharing among aviation entities and identified blockchain as a viable technology for sharing data, the main obstacles, as highlighted by literature and real-world pilot programs, are the governance structures of the data-sharing consortium. These governance structures encompass, but are not limited to, how data is shared, who has access to the uploaded data, how the financing of such an infrastructure is organized and how decisions are made within the consortium. The complexity and sensitivity of data in the aviation industry necessitate equitable governance frameworks to ensure all stakeholders feel secure and fairly treated.

Therefore, governance mechanisms must consider stakeholder values to foster a collaborative environment and a long-term sustainable data-sharing consortium in aviation. By seeking stakeholder input on governance arrangements, it is possible to identify their values. Once these values are identified, it should be acknowledged that there is a potential for opposing values, highlighting disagreements and differences among stakeholders. By structuring governance arrangements that include trade-offs for both sides without overriding critical values, a long-term blockchain consortium can be established. This leads to the research objective:

Structure blockchain governance arrangements that optimize participation in a data sharing consortium

To accomplish the stated objective and answer the main research question of:

How can governance mechanisms be designed to enhance participation in blockchain-based aviation part-tracking consortia?

a qualitative research approach distributed over multiple phases is adopted. The qualitative research approach involves desk research, interviews, surveys, and participatory observation, which is conducted in collaboration with IDCA. The primary research objective is addressed through the exploration of various sub-research questions, commencing with:

Sub-Research Question 1: What values do blockchain aviation part-tracking consortium stakeholders have?

To identify stakeholder values, the following four background research questions need to be answered.

Background-Research Question 1A: What is a blockchain aviation part-tracking consortium?
Background-Research Question 1B: Who are the stakeholders participating in a blockchain aviation part-tracking consortium?
Background-Research Question 1C: What stakeholder values has literature already identified in a data consortium?
Background-Research Question 1D: What stakeholder values are identified in practice in a data consortium?

Question 1A aims to distinguish between blockchain technology and Distributed Ledger Technology (DLT), define the key components of a blockchain, and give insight into the aim and definition of a blockchain consortium, which is answered through literature reviews.

The background sub-question 1B aims to create a comprehensive mapping of the key stakeholders involved in the process through a literature review, ensuring full stakeholder representation. The findings from this review will be used to identify interview candidates, which will serve as the primary research method for addressing background research question 1D.

Question 1D serves as a complementary resource for the interview structuring process discussed in **subsection 3.4.4**, facilitating a clear understanding of the anticipated responses from interviewees. This aids in formulating targeted questions and enables interviewers to navigate discussions effectively, ensuring that relevant information is obtained. Finally, background research question 1D aims to ensure a comprehensive understanding of stakeholder values, incorporating insights not only from the literature but also from aviation industry-specific stakeholders by conducting interviews. Interviews, which entail participants from the aviation industry, bring the responsibility to adhere to ethical methodologies. To this end, the research approach and data handling were approved by the Human Research Ethics Committee (HREC) of TU Delft before contacting any interview candidates. The HREC application includes an Informed Consent form as seen in **Appendix B section B.1** detailing the nature of the activity, including its risks, benefits, and procedures, as well as a Data Management Plan, and the HREC itself.

Starting research with the identification of values is crucial because the objective is not to establish arbitrary governance mechanisms but rather to create ones that align with stakeholder values, which will ensure stakeholder participation in the consortium. In addition to interviews, participatory observations during meetings of the Independent Data Consortium for Aviation (IDCA) are utilized to identify further stakeholder values. Having identified the values, it is imperative to acknowledge that design inherently entails trade-offs. Achieving complete satisfaction for all stakeholders and fully accommodating every value is unattainable. Consequently, prioritization among these values becomes mandatory. This leads the research to the second sub-question of:

Sub-Research Question 2: What are the critical values of stakeholders for designing governance mechanisms?

The goal of the second sub-research question is to rank the identified values for the structure of viable governance mechanisms. This selection process is facilitated through the employment of a survey that is sent to stakeholders in which the Bayesian Best-Worst method (BWM) is employed. BWM is a pairwise comparison-based method that offers a structured way to solve multi-criteria decision-making problems. For this study, the BWM is used to identify the objective weights because it brings several benefits, such as eliminating anchoring bias and the range of grading upfront (Rezaei, 2015). Initially, participants are asked to select the most important and least important values from the provided options. Subsequently, in the second phase, they are requested to indicate on a scale from 1 to 9 the degree to which they prioritize the most important value chosen over the other values and other values over the selected least important value. With the investigation of the values completed, the focus now shifts to examining the governance mechanisms.

The initial step in understanding the governance arrangements involves investigating the already existing governance mechanisms, leading to the subsequent sub-research question.

Sub-Research Question 3: How are governance mechanisms currently designed within blockchain consortiums?

The third research question aims to categorize the most common governance mechanisms and conduct a benchmark study to inform the creation of the final deliverable, which involves structuring governance mechanisms, taking the critical values of stakeholders into account. The initial step in understanding the governance mechanisms involves investigating the already existing governance mechanisms, leading to the subsequent sub-research question. A thorough literature review is undertaken, encompassing diverse blockchain implementation trials sourced from various databases, including Scopus, IEEE, and Google Scholar. To answer the third sub-research question and identify governance mechanism designs, the following three background research questions need to be answered.

Background-Research Question 3A: Why is blockchain governance needed?

Background-Research Question 3B: What does blockchain governance entail?

Background-Research Question 3C: What governance mechanisms are currently taken into account in the governance of a blockchain consortium?

It is clear that the concept of blockchain governance remains ambiguous among stakeholders, as evidenced by previous research indicating diverse opinions when seeking its definition (Akgiray, 2018; Beck et al., 2018; Bons et al., 2023; Carter, 2018; Hsieh et al., 2017; Laatikainen et al., 2021; Leewis et al., 2021; Liu et al., 2022; Pelt et al., 2020; Zachariadis et al., 2019; Ziolkowski et al., 2019). In order to reach a consensus and mutual understanding, it is imperative to define the meanings of blockchain governance. Once this is concluded, background research question 3C can be answered, which is the identification of governance mechanisms.

It is vital to outline the mechanisms and comprehend their definitions and rationale for implementation using real-life examples. The ultimate objective is to utilize these examples as benchmarks for refining governance arrangement designs for data sharing within the aviation industry. This approach aims to ensure that the governance structures developed are not only theoretically sound but also practically effective and aligned with industry needs.

At this stage of the research, stakeholders' values were already identified. Concurrently, governance mechanism designs were identified to fulfil these values. This advancement guides the research towards the subsequent step, which entails not only matching values with their corresponding governance mechanism designs but also conducting a comprehensive analysis of their impacts.

Sub-Research Question 4: How can governance mechanism designs be developed to ensure the fulfilment of stakeholder values in an aviation part-tracking consortium?

The final sub-research question seeks to integrate the identified stakeholder values from sub-research question 2 with the governance mechanisms from sub-research question 3. This approach adopts a value-centric design, ensuring that stakeholder values are fulfilled, which can subsequently lead to increased participation.

However, it is essential to recognize that structuring a governance design is not a straightforward task and often involves making trade-offs. Each design choice may have implications that extend beyond the immediate value it seeks to address, potentially impacting other values that stakeholders consider important. Therefore, a holistic impact analysis of governance mechanisms on stakeholder values needs to be conducted.

Ultimately, this analysis and evaluation process is crucial in shaping the research's final conclusions. By methodically assessing the impact of stakeholder values on governance mechanisms, the research offers design recommendations for part-tracking consortia, guiding decision-makers in developing part-tracking consortium governance. Furthermore, this study, to the best of the author's knowledge, is the first to adopt a values-centric approach in designing consortium governance, as opposed to the traditionally studied design-driven approach examined by other researchers (Ávila et al., 2022; Liu et al., 2022; Pelt et al., 2020; Rukanova et al., 2023; van Engelenburg et al., 2020). This novel perspective ensures that the governance mechanisms are aligned more closely with the core values of stakeholders while providing a new perspective to researchers. This approach enhances the overall effectiveness and relevance of the proposed governance designs while fulfilling the primary objective of this research: to structure blockchain governance mechanisms that optimize participation in an aviation parts-tracking consortium.

1.4. Research Flow Diagram

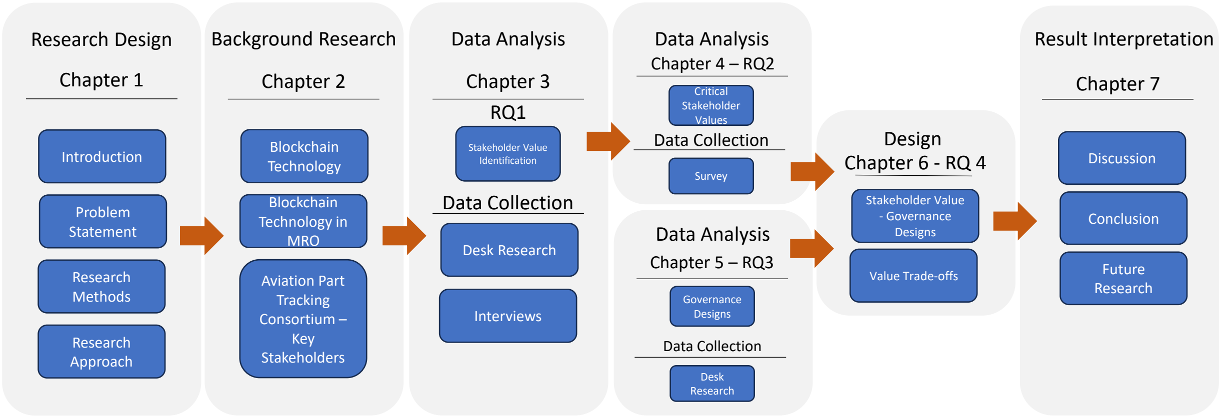


Figure 1.2: Research Flow Diagram

2 Background Information

2.1. Introduction

This chapter provides answers to

Background-Research Question 1A: What is a blockchain aviation part-tracking consortium?

Background-Research Question 1B: Who are the stakeholders participating in a blockchain aviation part-tracking consortium?

which provides the background information necessary to answer research question 1. Both questions are answered through desk research. The goal of this chapter is to understand the technology and generate a full list of stakeholders to ensure inclusivity during the interviews that are conducted in the next stage of the research.

The first question, the blockchain aviation part tracking consortium, is examined in three stages. This includes understanding the technology, assessing its value in business, particularly in aviation MRO, and determining the need and formation of a consortium. From **section 2.2** to **subsection 2.2.5** the history, development and main components of blockchain technology are investigated. From **section 2.3**, the examination delves into the main value generated by the technology for businesses, with a specific focus on the use cases within the aviation sector detailed in **section 2.4**. In **subsection 2.4.1**, an examination is dedicated to one of the pivotal use cases and the primary focus of this thesis: Parts Tracking in securing MRO operations. This section underscores the rationale behind the need to establish a blockchain consortium to address the MRO parts tracking use case.

The desk research continues with the identification of crucial stakeholders essential for participation in the consortium and begins with the delineation of the lifecycle of a part, which is examined in **subsection 2.5.1**. This allows for a comprehensive understanding of the stages involved in the journey of a component and aids in recognizing the stakeholders implicated. This chapter is finalized with the identification of key stakeholders along with their descriptions, responsibilities and potential data they could provide to the consortium elaborated in **subsection 2.5.2**.

2.2. Blockchain Technology

Before understanding what a part-tracking blockchain consortium is and which stakeholders participate in it, it is essential to comprehend the technology itself, namely blockchain, fully. This section provides a detailed overview of the definition, history, main components, and types of blockchain.

Over the last decade, blockchain technology has significantly transformed industries across the globe. Originally introduced as the underlying technology behind Bitcoin, blockchain has emerged as a disruptive technology with the potential to enable new innovations in various sectors (Frizzo-Barker et al., 2020). In simple terms, blockchain technology is:

"[...] a decentralised, transparent database that allows multiple parties to securely record and verify transactions without the need for a central authority or intermediaries." (Mougayar, 2016)

The rationale for opting for a distributed database over a centralized database within this research and the aviation sector is twofold. Firstly, the aggregation and processing of all pertinent data by a singular entity would give rise to a concentration of power, posing a substantial risk rather than serving as a prospective advantage for distinct industry segments and enterprises. Secondly, the primary objective is to implement a system intended for use by competitive businesses across the entire industry. To encourage industry-wide adoption, it is crucial to emphasize the need for a collaborative environment rather than a centralized one (Zavolokina et al., 2020). The widespread adoption of blockchain technology across the industry is pivotal as it enhances the network's comprehensiveness and ensures the precise tracking of part transactions from their birth to disposal. This extensive adoption facilitates economies of scale, reducing implementation and operational costs and making blockchain technology more accessible to smaller entities within the sector. Ultimately, such broad adoption enables the full realization of blockchain's potential, yielding benefits for the entire industry.

Distributed Ledgers and, more specifically, blockchain technology is chosen as the focal point of this research out of personal interest and academic underexplored potential. The main difference between Blockchain and DLT is that DLT is a decentralized database represented as a ledger, managed by multiple individuals without exclusively relying on the block structure (Agmon & Kallir, 2022) while blockchain by its name stores data in a chain over blocks as seen in **Figure 2.3**. Although DLT and blockchain are closely interconnected, it is imperative to distinguish between the two and must be stated that the term 'Blockchain' will be specifically used for the remainder of this report. An overview of the classification can be seen as follows in Figure 2.1.

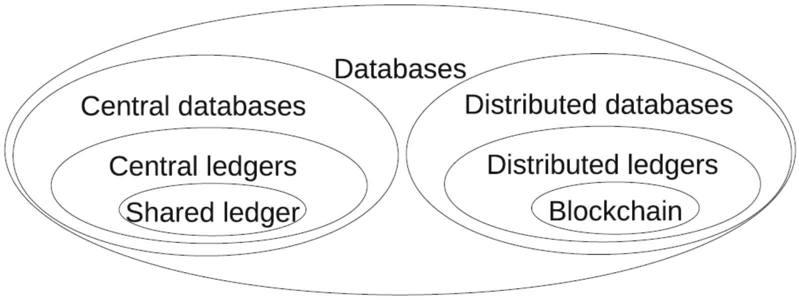


Figure 2.1: Database Classification, Copied from Koens and Poll (2018, p.116)

2.2.1. Developments Prior to the Invention of Blockchain

In 1983, David Chaum published a paper explaining his idea about 'blind signatures for untraceable payments'. In this paper, Chaum explains how cryptography would enable anonymous transactions, making third parties such as banks unable to view the payee, time, and amount of payments being made. The technology still relied heavily on third-party institutions (banks) to facilitate the transaction (Chaum, 1983). In 1991, the paper "How to Time-Stamp a Digital Document" by Stuart Haber and W. Scott Stornetta (Haber & Stornetta, 1991) laid the groundwork for blockchain technology. In this paper, a solution is proposed for the date stamping of digital documents, as it was easy to back or forward date these documents at the time.

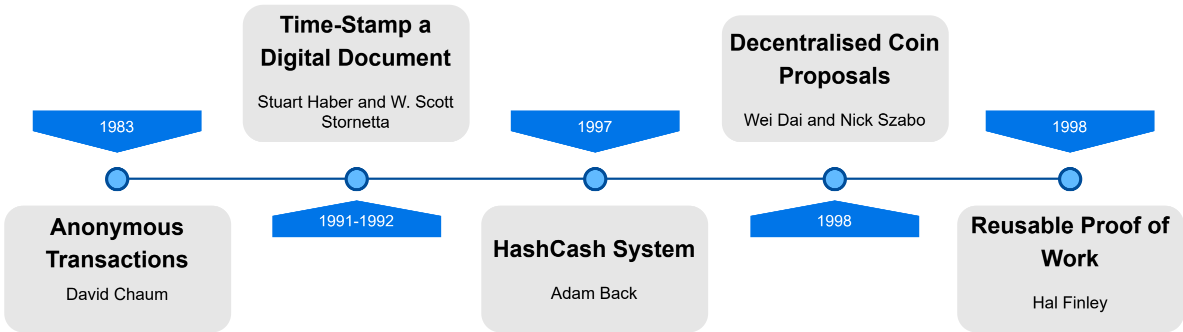


Figure 2.2: Timeline of the inventions enabling the blockchain technology

By 1997, Adam Back had developed the Hashcash system. This system was designed to prevent email spam. Similar to what Bitcoin is currently using, it uses a proof of work mechanism to verify that the email was not generated by a spammer (Back, 2002). B-money was a proposal by Wei Dai in 1998 for a digital currency that had many of the same conceptual technologies that Bitcoin used but never came further than the proposal stage (Dai, 1998). A similar proposal, called 'bit gold', was made by Nick Szabo, also in 1998 (Szabo, 1998).

Between 1998 and 2008, further improvements were made to the idea of decentralised data sharing. In 2004, Hal Finley created a working concept of Reusable Proof of Work (RPOW), where tokens could be exchanged securely (Finney, 2004). The RPOW technology and other improvements to decentralised data technologies enabled faster and more secure sharing.

2.2.2. The Invention of Blockchain

On 31 October 2008, a person or group of people laid out the foundation for the blockchain technologies as we know it. While the paper was officially written by Satoshi Nakamoto, their identity has never been confirmed. According to the author, there were multiple problems with electronic payments at the time, and the source of the problems was the requirement of a trusted third party. In the paper, the concept of how blockchain as a technology works and how this could empower a peer-to-peer currency, called *Bitcoin*, was explained (Nakamoto, 2008).

Between the release of the paper and January 3rd, 2009, the author implemented the idea of Bitcoin into code (Sheldon, 2021). Although Nakamoto is often acknowledged as the creator of blockchain, it can be argued that the implementation of blockchain was relatively simple and essentially involved the re-purposing of pre-existing technologies and ideas.

2.2.3. Functionality and Technological Principle

At its core, blockchain's decentralised nature eliminates the need for intermediaries, ensuring transparency and enabling peer-to-peer transactions. This decentralisation also enhances security through cryptographic techniques, creating immutable records that are resistant to tampering and fraud. In a public network, any type of new data input is recorded on a public blockchain ledger, where each new entry is verified and added to a block by network participants known as miners. These miners use cryptographic algorithms to validate the transactions and secure the network. Once a block is added to the blockchain, it becomes a permanent record (Antonopoulos, 2014).

The technological principle behind blockchain involves the use of cryptographic algorithms to create blocks of data that are linked together in a chronological chain. Each block contains a list of transactions, a timestamp, and a hash. The hash of each block is generated based on the data within and the previous block's hash, creating a cryptographic link that ensures the integrity of the entire chain (Spies, 2017). Hence, 'blockchain' is a digital database that keeps track of all the transactions or information in a series of blocks. Refer to **Figure 2.3** for a simple schematic of the blockchain principle.

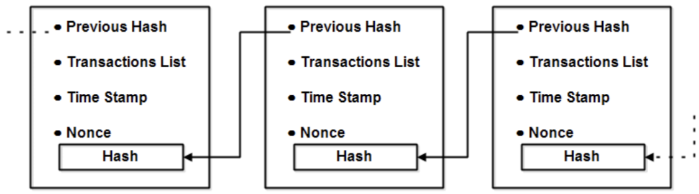


Figure 2.3: Fundamental components and technological principle of blockchain technology. Adapted from Hosameldeen (2018).

2.2.4. Main Types and Components of Blockchain Technology

To better understand the underlying technology and what was needed to enable it, this section elaborates on the blockchain types and technological components (Smetanin et al., 2020).

There are three different types of Blockchain: Public, Private and consortium or federated. Tripathi et al. (2023) describes them as follows:

- **Public** blockchain functions on a decentralized network where participants lack special privileges so that everybody can access and participate. It serves as the backbone for numerous cryptocurrencies like Bitcoin and Ethereum (Nakamoto, 2008; Vitalik Buterin, 2024). Its distributed architecture ensures transparency, granting all participants access to data. Additionally, consensus mechanisms allow all miners to partake in the validation process, making it impossible to tamper with the data because altering the blockchain would require controlling at least 51% of the network's processing power. This means that a malicious actor would need to gain majority control of the network, which is practically impossible and prohibitively expensive, thus ensuring the security and integrity of the data.
- **Private** blockchain functions on a partially centralized network where a single administrator defines all the aspects of the blockchain (Data sharing rules, cryptography usage, how data is stored etc.). A central authority makes the decision regarding participatory entities, and all actors in the network know each other's real identities. The primary advantage of this blockchain technology, compared to the public one, lies in its fast and efficient operation due to the lower volume of data and simpler cryptography. Multichain stands as an exemplar within this category of blockchain systems (Greenspan, 2024).
- **Consortium/Federated** blockchain is a decentralized network where participants can vary in their access, writing and consensus rights. The ultimate goal is to ensure that everyone has equal rights; however, this ideal may not always be realized in practice. The blockchain maintains limited to no accessibility for external parties that are not involved in the consortium while remaining accessible to internal participants. This type of blockchain also has high energy efficiency and is moderately secure. Hyperledger and Corda are examples of this type of Blockchain (Hyperledger, 2021; Richard Gendal Brown, 2024).

The main technological components of Blockchain technology are described as follows;

- **Nodes** are devices that participate in the blockchain network. Each node contributes to the validation of transactions by maintaining a copy of the entire blockchain.
- **Transactions** are the digital records of exchanges and interactions that are stored on the blockchain. They can represent various types of information/data, such as payments, transfers, contracts, or asset ownership.
- **Ledger** refers to a database that maintains a record of all transactions across a network of computers.
- **Blocks** are grouped together transactions, which are added to the ledger and chained following an order. Every block forms a chain-like structure as it contains a group of verified transactions and a reference of the previous block's hash.
- **Hash** is a unique identifier, i.e., a deterministic hexadecimal number. For each unique input data, the hash function produces a unique hash number, and it will always have the same number of characters.
- **Timestamp** is a process of digitally signing a document that includes capturing the exact date and time of its

creation, thus serving as evidence for the document's origin.

- **Consensus Mechanism** is the protocol used to attain unity among participants on the verification of transactions and the sequence in which they exist in the blockchain. Proof of Work (PoW) and Proof of Stake (PoS) are common consensus mechanisms used in different blockchain applications, however, there are multiple more such as Delegated PoS, Proof of Activity, Proof of Burn, Proof of Capacity, Proof of Elapsed Time and Practical Byzantine Fault Tolerance. In Table 2.1, descriptions of different consensus mechanisms along with their advantages, disadvantages and implemented projects are given. It is crucial to agree upon the most appropriate consensus mechanism method according to the situation in which stakeholders are situated, as this will ensure the efficiency, security, and fairness of the blockchain.

Table 2.1: Blockchain Consensus Mechanisms, *Based on* John Fáwọlé (2024) and Shiksha (2023)

Consensus Mechanism	Description	Advantages	Disadvantages	Projects Implemented
Proof of Work	Proof of work is provided by sending the information in a block through a hashing algorithm, then adjusting variable fields until a hexadecimal number is reached that has a lower value than the network's difficulty target.	Decentralized Structure High Level Security Medium Scalability	High Block Time Energy Inefficiency Hardware Dependency	Bitcoin Dogecoin Litecoin
Proof of Stake	Proof of Stake is a consensus algorithm where validators lock up some specified amount of native assets to secure the blockchain.	Fast Block Creation Low Scalability Energy Efficiency	Centralization Low cost of Misbehaving	Tezos Cordano Ethereum
Delegated Proof of Stake	Not all who lock some specified amounts of native assets can become validators. Instead, some selected delegates better called "witnesses" perform the decision-making on behalf of the others.	High Scalability Energy Efficiency Low-cost Transactions	Semi-centralization Susceptible to 51% Attack	EOS ARK Tron
Practical Byzantine Fault Tolerance	The objective of a BFT mechanism is to safeguard against the system failures by employing collective decision making (both – correct and faulty nodes) which aims to reduce to influence of the faulty nodes.	Energy Efficiency High Throughput	Not Scalable Susceptible to Sybil Atttack	Hyperledger Fabric Ziliqa
Proof of Weight	Addresses the Byzantine Generals' Problem by randomly selecting committee members based on their account balances, differing from Proof of Stake by not requiring users to lock or stake their tokens.	Customization Scalability Quick Transaction Confirmation	Semi-centralization No Incentive	Algorand Filecoin Chia
Proof of Capacity	Miners prove their storage capacity using hard disks by plotting nonces before mining starts; they can only create as many nonces as their space allows, and the miner with the closest hash in their nonce to the network's broadcasted puzzle wins.	No Special Hardware More Decentralized	Susceptible to Grinding Attack Space Privilege Applies	Burstcoin Permacoin
Proof of Authority	Consensus mechanism in which validators stake their identity, fixes the loophole of due diligence in the design of a blockchain.	Transactional Speed Higher Security	Not Decentralized Breaks Anonymity	VeChain Palm Network Xodex
Proof of Importance	Improvement for PoS by rating a node based on the account value, number of transactions and the volume of the transactions.	Sybil Resistant Prevents Hoarding	Favors the Rich Little Incentive	NEM
Proof of Activity	Combination of PoS and PoW	51 % Attack Resistant High Fault Tolerance Incentive	High Energy Consumption Hardware Dependency Validation Time Inefficient	Decred Komodo Espers
Proof of Burn	Miners reach a consensus by burning the coins. It's a process in which crypto coins get permanently eliminated from regular circulation. In such cases, the burning of coins mechanism is used to validate transactions.	Energy Efficiency Incentive Long-term Commitments	Not an Initial Consesus Algorithm No Implementation Validation Time Inefficient	Slimcoin Counterparty Factom
Proof of Elapsed Time	PoET is a consensus algorithm used in a permissioned blockchain network to decide on mining rights and the next block miner.	Energy Efficiency Fast Transaction Speed	No Decentralization No Anonimity Dependence on Intel Tools	Intel

2.2.5. Further Development of Blockchain Technology & Usage as Database

By 2015, the Ethereum blockchain was created, which introduced smart contracts, expanding the possibilities from simple money transactions to self-executing contracts and marking the second generation of blockchain technology (Buterin, 2014; Frankenfield, 2023; Tripathi et al., 2023).

Smart contracts are defined as:

"an automatable and enforceable agreement. Automatable by computer, although some parts may require human input and control. Enforceable either by legal enforcement of rights and obligations or via tamper-proof execution of computer code." (Clack et al., 2017)

The implementation of smart contracts is regarded as a significant development that has influenced the value and widespread adoption of blockchain. This advancement expanded the vision of its functionality, leading to new methods of coordination among organizations and enhanced data sharing. Apart from its use in finance, blockchain was now considered to be applied in social services and contractual agreements, integrated with IoT devices, and finally utilized as a database due to its inherent storage mechanism.

A notable example of this development is the creation of consortium blockchains. Consortium blockchains create a new economic system where enterprises can share, buy, and sell valuable data and use that pooled data to create new goods and services, which can then be monetized (Hurder, 2020). One example of this is the development of the Hyperledger platform by the Linux Foundation. Utilizing this platform, major companies like Walmart have implemented a supply chain tracking system, effectively eliminating existing inefficiencies. Additionally, Amazon announced the general availability of its Amazon Managed Blockchain service on AWS to help users build resilient Web 3.0 applications. From 2021 onwards, multiple cloud providers, including Oracle, Kaleido, Alibaba Cloud, and Alchemy, have offered blockchain as a service, transforming it into a versatile tool for various applications (Sheldon, 2021). However, it should not be disregarded that blockchain has fundamental differences compared to a centralized database, including its decentralization, cryptographic security, lack of administrative control, immutability, and the ability to transfer data without needing permission from any central authority while also having its downsides such as rich queries (Kalajdjieski et al., 2023).

2.3. Blockchain Technology in Business Value Creation: Transparency & Traceability

Research within the domain of blockchain technology is evolving beyond its initial association primarily with cryptocurrency, expanding into various enterprises exploring its diverse applications. An overview of the main advantages of blockchain technology in supply chain management can be seen in **Table 2.2**.

Table 2.2: Value Creating Components Of Blockchain in Supply Chain, *Based on Kawa and Maryniak, 2019; Kshetri, 2018*

Impact Areas of BC on SC	Effect	How? (Examples)
Cost	Decrease	Eliminate Paper Records Eliminate Compliance Cost
Traceability & Visibility	Increase	Creation of a Digital Twin Usage of RFID Tags
Transparency	Increase	Decentralizing Information Storage Distributing Data Responsability
Demand Forecasting	Optimize	Reduce Bullwhip Effect Creation of Trustless Environment
Speed	Increase	Digitizing Physical Process Reduce Interactions
Fraud	Decrease	Creation of a Digital Twin Digital Verification and Authentication
Flexibility	Increase	Increase Reaction Capability
Sustainability	Optimize	Tracing Carbon Footprint Quantifying Sustainability

It is important to establish a distinct differentiation between transparency and traceability in this table, as they are often employed interchangeably and inaccurately. Hofstede (2007, p.386) defines supply chain transparency as "[..] the extent to which all its stakeholders have a shared understanding of and access to, the product related information that they request, without loss, noise, delay and distortion". On the other hand, traceability entails the capacity to retrieve detailed information at a granular level pertaining to any component that remains within a supply chain (Pant et al., 2015).

2.4. Blockchain Technology in Aviation Industry

Various researchers have extensively investigated the application of blockchain technology within the aviation sector. The different use cases and possible applications of this technology can be seen in **Figure 2.4** and investigated in detail in **Appendix A section A.1**.

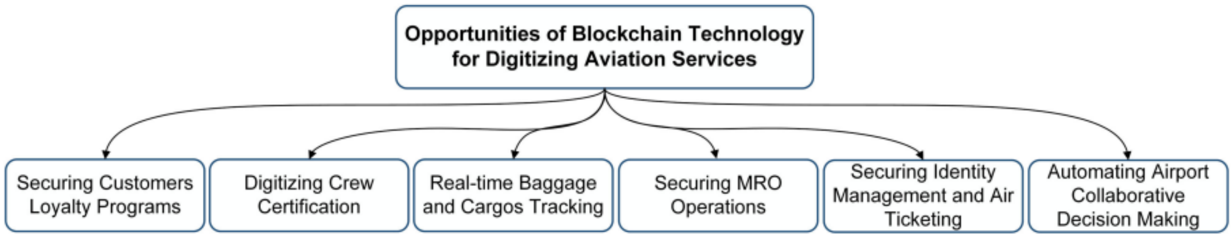


Figure 2.4: Opportunities of Blockchain Technology in the Aviation Industry Adapted from Ahmad et al. (2021b).

Nonetheless, a specific subject explored in the research is given in-depth attention: **Securing MRO Operations** and more specifically sharing data over the full lifecycle of a part. This area is the focal point of investigation in the upcoming section.

2.4.1. Blockchain Technology in Maintenance Repair Overhaul Operations

MRO operations encompass all the tasks undertaken by the maintenance crew to maintain the aircraft's operational status. These operations within the lifecycle of an aircraft are complex, attributed not only to the aircraft's configuration but also to the management of parts, supply chain logistics, communication dynamics among stakeholders, financial transactions and certifications. (Efthymiou et al., 2022; Rajkov, 2018; Rolinck et al., 2021). Currently, the documentation of these operations is perceived as susceptible to manipulation, prone to errors, and heavily reliant on manual processes due to the lack of an inter-organizational data management system, which leads to the scrapping of valuable parts and incurring increased costs (Wickboldt et al., 2020).

Up until now, the research surrounding blockchain usage in MRO operations encompasses not only the utilization of blockchain to facilitate the maintenance of aircraft parts inventory but also to closely monitor the performance and usage parameters of these parts (Aydemir et al., 2020; Ho et al., 2021a; Madhwal & Panfilov, 2017; Schyga, 2019). The primary shared application and research focuses on the concept of a 'digital passport'. The goal of this is to collect data on a product and its supply chain and share it across the entire value chain, allowing all participants to access the information. In line with the International Air Transport Association (IATA), which emphasizes the crucial role of accurate traceability data throughout an aircraft part's life cycle, Ho et al. (2021a) proposes a managerial platform based on blockchain technology. This platform would aim to accurately record and maintain traceability data for aircraft parts. Madhwal and Panfilov (2017) investigation revolves around a particular situation where they explore the potential of blockchain to establish a transparent supply chain network for aircraft parts to mitigate the risk of aircraft parts being available in the black market and help managers analyse the supply, demand, and source of availability of parts. Additionally, certain initiatives and prototypes have already been created, such as Schyga (2019), which has constructed a prototype for permissioned Blockchain in Aircraft MRO investigating technical strengths, weaknesses and challenges in the application of Blockchain technology for aircraft maintenance.

Unsurprisingly, the adoption and implementation of blockchain technology by a single entity would not precipitate substantial alterations. Rather, its application should extend across the entirety of the aircraft part lifecycle. This perspective is also supported by Schyga (2019), who underscores that the feasibility and value generation associated with establishing a blockchain depends on achieving a critical mass involving key market participants. Schyga (2019) further suggests that the adoption of blockchain technology for aircraft MRO could be envisioned in similar industries that rely on complex fleet maintenance involving various stakeholders, such as the shipping or rail sectors.

Upon examining these sectors, a comparable commercial implementation of blockchain technology, TradeLens, was discovered in the shipping industry, jointly developed by IBM and GTD Solutions, a subsidiary of A.P. Moller Maersk. This application facilitated the sharing of business documents among supply chain partners, including sellers, carriers, and terminals. However, A.P. Moller Maersk and IBM have chosen to discontinue their participation in TradeLens in November 2022. Rotem Hershko, the Head of Business Platforms at A.P. Moller, cited the withdrawal, stating, "Unfortunately, while we successfully developed a viable platform, the need for full global industry collaboration has not been achieved." (Maersk, 2022, p.1). This suggests that despite the platform's viability, there seems to be a lack of widespread cooperation or participation from other industry stakeholders which underscores the significance of the network effect in realizing blockchain technologies' full potential and optimizing its value-generation capabilities. This observation was also noted in previous literature studies by Blazquez (2024) and van Engelenburg et al. (2020). In the context of this research, network effect refers to "any situation in which the value of a product, service, or platform depends on the number of buyers, sellers, or users who leverage it. "(Stobierski, 2020, p.1).

Given the validation that blockchain technology's value is best demonstrated when participants across the entire industry engage in research and real-life cases, the creation of an aviation part-tracking consortium is crucial. Therefore, the next section investigates who should be involved in this consortium.

2.5. Aviation Part Tracking Blockchain Consortium - Key Stakeholders

To identify stakeholders, the lifecycle of a part is examined. The lifecycle of an aircraft part encompasses multiple phases, starting from its initial production to its ultimate disposal. Each phase is crucial and involves different stakeholders who contribute to ensuring that the part adheres to safety, regulatory, and performance standards. By identifying the stages that a part goes through, it is possible to determine the stakeholders involved in each phase, thereby understanding who should be included in the consortium.

2.5.1. Aircraft Part Lifecycle

There are three main stages in an aircraft part lifecycle, which are as follows (KLM, 2024). A graphical representation of the three stages with the distinct steps taken can be seen in Appendix Figure A.1.

- **Manufacturing/Availability/Logistics:** This phase involves the manufacturing of the aircraft part, including the procurement of necessary supply components from their fitting tier 1 supplier. Once the original equipment manufacturer manufactures a part, it is either sold directly to an operator if there is an immediate need or to a pool provider to ensure sufficient inventory. Upon receipt, the pool provider assesses its status to ensure compliance with usability regulations. This evaluation is essential because pool providers manage not only new parts but also second-hand parts that are repaired and recycled. After the part is inspected and validated, it is transported to storage. The part remains in storage until it is sold to ensure its availability on demand. The prompt fulfilment of part demand is essential, as aircraft cannot operate and incur costs without the required components, leaving no time to wait for production. Once sold, the part is shipped to the operator.
- **Airline Operation/Fleet Management:** During this phase, the component is installed on the aircraft of the operator by a dedicated maintenance repair overhaul service. The part will be used in daily flight operations to generate extensive data during usage. Rotable parts are components that can be repeatedly restored to a fully operational state throughout the aircraft's service life. This means they are designed to be used multiple times after being refurbished. Examples of rotable parts include avionics, landing gear, and major engine accessories. Repairable parts, on the other hand, can also be restored to a fully operational state, but their service life is shorter compared to the aircraft's overall lifespan. These parts need to be repaired or replaced more frequently. Examples of repairable parts include engine blades, tires, and galleys. Lastly, expendable parts are those for which no approved repair procedures exist, or the repair cost would be higher than the cost of replacing the part. These parts are typically discarded and replaced once they become unserviceable (Cosaro, 2018). The dedicated maintenance crew steps in when a part experiences a problem or reaches the end of its lifecycle. If the issue is minor or involves a simple inspection, it is handled directly on the aircraft. However, if the problem is more serious, the part is promptly removed and replaced with a spare part, if available, that was purchased from the pool provider.
- **MRO/Logistics Operations:** The final phase of a part's lifecycle begins after it is removed from the aircraft, whether due to malfunction or the completion of its lifespan. Once removed, the part is transported to the base station of the MRO facility. Here, it undergoes a comprehensive inspection to determine if it can be repaired. If the inspection concludes that repairs are possible, the necessary repairs are carried out. The part is then either returned to the pool for future use or immediately sent back to the operator if there is an urgent need for reinstallation and continued operation on an aircraft. However, if the inspection determines that repair is impractical or impossible, the part is decommissioned. This marks the beginning of the end-of-life process, ultimately leading to the part being scrapped. This decommissioning ensures that only serviceable parts remain in circulation, maintaining the safety and efficiency of the aircraft fleet. The scrapping process involves the responsible disposal of the part, often in accordance with environmental regulations and industry standards.

2.5.2. Stakeholder Identification

For blockchain consortiums their stakeholders are crucial as they support strategy and contribute to the resources for new projects; yet, if their views and expectations are not taken into consideration, they can generate resistance and hinder the business process development.

Based on initial research done within the IDCA part tracking working group, which is supplemented by additional desk research, the corresponding stakeholders in these phases are distinguished Independent Data Consortium for Aviation, Independent Data Consortium for Aviation (2021). This process highlighted eight stakeholder groups that physically interacted with an aircraft part throughout its lifecycle: Tier 1 Supplier, Original Equipment Manufacturer, Regulator, Lessor, Operator, MRO, Pool Provider and Disposer. A full list of all actors with the definition of their roles is given in **Table 2.3**.

Table 2.3: Key Stakeholders in Aviation Part Tracking Consortium

Key Stakeholder	Description & Responsabilities	Example
Manufacturer (OEM)	Stakeholder who produces multiple components of aircraft such as engines, avionics systems etc.. Sales and marketing of components as well as regulatory conformance and warranty are within the responsibilities of OEMs	Collins Aerospace
Supplier – Tier 1	Stakeholder that provides components, sub-systems and systems to OEM, MRO and Airlines. Sales and marketing of components as well as regulatory conformance and warranty are within the responsibilities of Tier 1 Suppliers	Honeywell
Regulator	State-designated agency tasked with certification of airworthiness for aircraft, parts, organizations, and personnel as well as regulating all civil aviation-related design, production, operation activities in the respective geographic jurisdiction	EASA
Lessor	Lessor of aircraft or engine assets to operators	Air Lease Corporation
Operator	Stakeholder that ensures passenger transport with fleet operations and ticketing while meeting aircraft airworthiness standards and compliance with regulations	Turkish Airlines
Maintenance, Repair and Overhaul (MRO)	Provider of aftermarket scheduled and unscheduled repair as well as overhaul services while creating airworthiness records and verifications of them. Also involved in part replacement	Lufthansa Technique
Pool Provider	Supplier and distributor of new and Used Serviceable Materials in case of immediate need. Purchase and sale of spare parts	AFI KLM E&M Components
Disposer	Responsible for disposing of aircraft at the end of its life as well as recycling components and environmentally friendly disposal	AELS

A Tier 1 supplier provides essential materials, components, or sub-systems to the OEM. The OEM, in turn, manufactures ready-to-use parts that are directly installable on aircraft. Once an OEM produces a part, it is either purchased by a pool provider or directly by an operator. Pool providers serve as intermediaries between OEMs and operators. Their existence is vital because operators need to keep their aircraft operational; any downtime results in financial losses. Therefore, rapid replacement of parts is necessary. Pool providers facilitate this by maintaining a stock of parts, ensuring immediate availability. They procure parts not only from OEMs but also from operators, ensuring all transactions comply with regulatory standards. When parts are acquired by an OEM, MRO organizations assist in installing these parts on the aircraft. MROs play a critical role in maintaining the airworthiness and operational efficiency of the aircraft. Their expertise ensures that parts are correctly installed and maintained, adhering to strict regulatory requirements and industry standards. In cases where the aircraft is leased rather than owned by the operator, the lessor must be informed of any changes. Lessors bear responsibility for the airworthiness of their aircraft and wish to maintain their asset's value, necessitating notification of any modifications. This communication ensures that the lessor can keep accurate records of the aircraft's maintenance history and address any potential impacts on its residual value. At the end of a part's lifecycle, disposal entities become involved, ensuring proper handling and disposal. The role of disposers is to manage the end-of-life phase of aircraft components, ensuring that materials are recycled or disposed of in an environmentally responsible manner. This process helps minimize the environmental footprint of the aerospace industry and ensure compliance with environmental regulations. Throughout this process, regulatory bodies oversee and ensure compliance with all aviation safety and operational standards. Regulatory agencies, such as the Federal Aviation Administration (FAA) or the European Union Aviation Safety Agency (EASA), establish guidelines and regulations that govern every aspect of the supply chain, from the manufacturing of parts to their installation, maintenance, and disposal.

It should be noted that two additional stakeholders, namely Original Airframe Manufacturers (OAM) and Freight Forwarders, could have been included in the list. However, due to the thesis' specific focus on parts, OAMs, which are responsible for designing, developing, and producing the entire aircraft structure, known as the airframe, which encompasses the fuselage, wings, and tail, rather than individual parts, were excluded from consideration. Additionally, considering stakeholders' limited concern regarding the intricacies of transportation steps and the diverse array of freight forwarders operating worldwide, these entities were also omitted from the analysis.

Stakeholder Data

In addition to identifying the stakeholders involved in the aerospace supply chain, it is essential to examine the specific contributions each stakeholder brings to the consortium, particularly regarding the types of data they can provide. This subsection is based on initial research done within the IDCA part tracking working group Independent Data Consortium for Aviation, Independent Data Consortium for Aviation (2021).

Tier 1 suppliers play a fundamental role by supplying birth records and certificates for all components. These records are essential for validating the authenticity and compliance of parts with regulatory standards. Additionally, Tier 1 suppliers must provide a Component Maintenance Manual (CMM) and the Installed Service Bulletin (ISB) to MRO organizations. The ISB details modifications that can be made to aircraft parts, ensuring that MROs have the necessary information to implement these changes accurately. This data must also be shared with lessors to maintain comprehensive maintenance and modification records. OEMs are responsible for providing installation dates for each component. This information is critical for tracking the lifecycle of parts and scheduling maintenance activities. Accurate installation dates help operators and MROs plan and execute maintenance tasks in accordance with regulatory requirements and operational needs. Operators, despite possessing extensive data on aircraft usage, are required to share only two key pieces of information: the reason for the removal of a component and the accumulated hours and flight cycles. This data is vital for understanding the operational history of parts and identifying patterns that may indicate potential issues or the need for specific maintenance actions. MROs contribute significantly to the part lifecycle data by recording shop findings, which detail the primary reasons for component breakdowns. They also provide certificates confirming the airworthiness of parts after maintenance has been conducted. This information is essential for ensuring that parts meet safety standards and for tracking the performance and reliability of components over time. Pool providers maintain comprehensive data on transaction dates and changes in ownership of parts. This data offers a broader perspective on the movement and utilization of components within the supply chain. By tracking these transactions, pool providers help ensure that parts are readily available for operators, minimizing aircraft downtime. Lessors provide data on ownership provenance, which is crucial for maintaining accurate records of aircraft and component ownership. This information is essential for ensuring that lessors are aware of any changes that could impact the value or airworthiness of their leased assets. Finally, disposers complete the data flow by providing scrap-out dates for components that have reached the end of their lifecycle. This data is vital for ensuring that parts are disposed of in an environmentally responsible manner and that records are updated to reflect the removal of components from active service.

2.6. Conclusion

In this chapter, two background research questions are answered.

Background-Research Question 1A: What is a blockchain aviation part-tracking consortium?

Background-Research Question 1B: Who are the stakeholders participating in a blockchain aviation part-tracking consortium?

A blockchain aviation part tracking consortium is a collaborative alliance formed to enhance the traceability and transparency of aviation parts through blockchain technology. Blockchain technology is a decentralised, transparent database that allows multiple parties to securely record and verify transactions without the need for a central authority or intermediaries. The technology encompasses various types and components. This thesis primarily focuses on consortium blockchain, which restricts access for external parties not involved in the consortium while remaining accessible to internal participants. This approach is chosen to safeguard the highly sensitive nature of the data being shared, considering the stringent regulations of the aviation industry and potential compliance with the General Data Protection Regulations. The most critical component is the consensus mechanism, which is the protocol used to achieve agreement among participants on the verification of transactions and their order within the blockchain. It is essential to select the most suitable consensus mechanism based on the stakeholders' specific context, as this will ensure the blockchain's efficiency, security, and fairness.

An aviation part-tracking consortium aims to create a comprehensive and immutable record of the birth, transactions (ownership changes, activities performed on the part), and disposal of aviation components, thereby improving efficiency, reducing costs, enhancing safety, and ensuring regulatory compliance within the industry. The stakeholders that should participate in this consortium are identified through the lifecycle of a part, which includes three stages: Manufacturing/Availability/Logistics, Airline Operation/Fleet Management, and MRO/Logistics Operations. These stages involve Tier 1 Suppliers and Original Equipment Manufacturers (OEMs), who play a fundamental role by supplying birth records and certificates for all components. Operators are responsible for providing installation dates and reasons for removing each component. Maintenance, Repair, and Overhaul (MRO) organizations contribute significantly to the part lifecycle data by recording shop findings that detail the primary reasons for component breakdowns. Lessors provide data on ownership provenance, which is crucial for maintaining accurate records of aircraft and component ownership. Pool Providers manage second-hand items and sell them. Regulators maintain an oversight role and intervene in case of an accident or other issues. Finally, disposers complete the data flow by providing scrap-out dates for components that have reached the end of their lifecycle.

Understanding the roles of each stakeholder is essential for the consortium's success and inclusivity. Excluding any stakeholder can compromise the consortium's integrity and effectiveness, potentially leading to its dissolution. With the stakeholders identified, the research moves forward to the next step, which examines the specific values of these stakeholders.

3 Stakeholder Values

3.1. Introduction

The following chapter addresses the first sub-research question:

Sub-Research Question 1: What governance values do stakeholders have for participating in a Blockchain aviation part tracking consortium?

In this chapter, desk research and interviews are utilized to identify stakeholder values, which will later inform the creation of governance arrangements in subsequent chapters. Identifying these values and designing governance structures for them is pivotal because it ensures that the governance framework aligns with the interests and priorities of those involved, thereby enhancing their commitment and participation. The aim of this chapter is to identify a set of values that stakeholders hold when participating in an aviation part-tracking consortium.

The first step entails examining a benchmark framework, for systematically and consistently reviewing the literature and collecting stakeholder values. As elaborated in **section 3.2**, this step establishes the foundation for identifying values. Employing an existing framework while ensuring thorough investigation facilitates comparative analysis, enabling the research to understand the stakeholder value interactions. The literature review results are presented in **section 3.3**. It is identified that previous literature has neither specifically addressed the values of aviation entities, nor has particularly looked into data sharing within a part-tracking blockchain consortium. Therefore, additional investigation is required on a practical basis to fill this gap.

To solve this matter, a collaboration with the Independent Data Consortium for Aviation (IDCA) is initiated. IDCA describes itself as "a global consortium of leading aviation companies at all levels of the industry coming together to develop the foundation for allowing data to be shared in a non-competitive manner. Its objective is to create a more efficient marketplace, where both waste and the time required to get to a common solution is minimized." (Independent Data Consortium for Aviation, Independent Data Consortium for Aviation, 2021). Within this consortium, one of the ongoing work packages is focused on "Parts tracking from birth to disposal," which aligns precisely with the topic of this thesis.

After establishing contact, it was decided that the researcher would engage in bi-weekly online workgroup meetings as well as a two-day workgroup held offline in the Netherlands. Furthermore, different participants in the aviation industry have been interviewed. The findings from the participatory observations are elaborated upon in **subsection 3.4.2**. Interview analysis is conducted more elaborately over multiple subsections discussing its structure in **subsection 3.4.4**, participants in **subsection 3.4.5** and analysis in **subsection 3.4.6**. Finally, the results of interviews are discussed in **section 3.5** which is further elaborated on in **subsection 3.5.4** with a statistical quote analysis.

This chapter is finalized with a conclusion chapter where the stakeholder value layers are demonstrated in **section 3.6** which is used as an input to the stakeholder survey discussed in the next chapter.

3.2. Selecting Framework

To systematically and consistently review the literature and collect stakeholder values, a structured framework is chosen. This framework serves as a guiding tool, enabling researchers to comprehensively identify and categorize the various values held by stakeholders. Given that blockchain technology is still emerging and has not yet achieved widespread adoption, it remains in the acceptance phase. Consequently, it is imperative to select an appropriate technology acceptance model to guide this research.

Up until now, researchers have studied multiple different frameworks for technology acceptance such as the Technology Acceptance Model (TAM), Theory of Planned Behaviour (TPB), Unified Theory of Acceptance and Use of Technology (UTAUT), Diffusion of Innovation (DOI), and the Technology, Organization, and Environment (TOE) framework. A high-level overview of these models can be seen in **Table 3.1**.

To select an appropriate framework for investigating stakeholder values in an aviation part-tracking consortium, the first key aspect to consider is the focus level. Since this research specifically targets the collaboration of different organizations along the life cycle of a part, it is clear that a framework focusing on the firm level should be selected. The most suitable options are either the Diffusion of Innovation (DOI) or the Technology, Organization, and Environment (TOE) framework (Oliveira & Martins, 2011). The primary decision between the DOI and the TOE framework is based on the goals and focus of the research. Through the investigation of technological, organizational, and environmental aspects, TOE provides a holistic picture, while DOI focuses solely on innovation features. Yet another weakness of DOI is that it is hard to apply in specific contexts which creates a huge barrier while investigating blockchain adoption in aviation part tracking consortium. TOE is a reliable framework for comprehending the challenges of technology adoption in practical contexts due to its empirical validation and adaptability to a variety of technological contexts

Table 3.1: Technology Acceptance Frameworks (Davis & Venkatesh, 1996; Fishbein & Ajzen, 1975; Rice & Rogers, 1980; Tornatzky & Fleischer, 1990; Venkatesh et al., 2003)

Framework	Technology Acceptance Model	Theory of Planned Behaviour	Unified Theory of Acceptance and Use of Technology	Diffusion of Innovation	Technology, Organization, and Environment
Core Focus Level	Individual User Acceptance of Technology	Individual Behavioral Intentions driven by Attitudes and Norms	Individual Level Integration of Technology Usage	Firm Level Spread of Technologies	Firm Level Contextual Factors Influencing Technology Adoption
Key Constructs	Perceived Usefulness Perceived Ease of Use	Attitude Subjective norms Perceived Behavioral Control	Performance Expectancy Effort Expectancy Social Influence Facilitating Conditions	Innovation Communication Channels Time Social System	Technological Context Organizational Context Environmental Context
Strenghts	Simple Easy to Apply	Comprehensive Considers Social Influence	Comprehensive Empirically Validated	Addresses the Process of Innovation Over Time	Holistic Considers Multiple Levels of Influence
Weaknesses	Ignores external factors beyond perceived ease of use and usefulness	Complex to apply Relies on Self-reported Data	Complex Requires Extensive Data Collection	Difficult to Apply in Specific Contexts	Overlook Specific Factors

(Oliveira & Martins, 2011).

3.2.1. TOE Framework

To better comprehend the TOE framework an in-depth analysis is conducted in this section. According to Eveland and Tornatzky (1990) "The Processes of Technological Innovation," the Technology Organization and Environment (TOE) framework outlines an important part of the larger innovation process and emphasizes how a firm influences how innovations are adopted and integrated. It clarifies that three different aspects of a firm have an impact on adoption decisions.

- **The Technological Context:** Includes all relevant technologies for the company, including those that are available on the market but have not yet been adopted as well as those that have already been incorporated into operations. The technologies that are currently in use inside a company play a pivotal role in the adoption process because they set a benchmark that determines how quickly and to what extent technological innovations can be adopted by that specific firm (Collins et al., 1988).
- **The Organizational Context:** The characteristics and resources of the organization are referred to as the organizational context. These include internal communication systems as well as inter-firm communication processes, the size of the company, and the resources that are available (Baker, 2011).
- **The Environmental Context:** The environmental context mainly encompasses the regulatory landscape, industry structure and the availability of technology service providers (Baker, 2011).

To summarize, the three contexts and their variables can influence technology uptake in both positive and negative ways. However, it is important to clarify that for the remainder of this thesis, the environmental context will not be investigated. Although the regulatory landscape and technology providers play a critical role in the adoption of blockchain technology within the aviation industry, this thesis specifically focuses on data-sharing solutions. The decision to exclude the environmental context is deliberate and stems from several considerations. Firstly, the regulatory landscape, while significant, often involves complex, evolving, and region-specific regulations that would require a separate, extensive analysis to address adequately. Similarly, technology providers operate within a broad spectrum of influences and motivations, adding layers of complexity that fall outside the scope of this research. Furthermore, given that data-sharing blockchain platforms have yet to achieve significant penetration across industries, a more focused study on the technological and organizational contexts is warranted. By narrowing the focus, this research aims to provide a more detailed and actionable understanding of values within the technology and organizational context.

3.3. Stakeholder Values in Literature

As outlined earlier, a very limited amount of researchers have focused on the investigation of stakeholder values for governance design in a data-sharing consortium. In general, design is a process that involves constant decision-making. According to R. Keeney (1994), there are two approaches to decision-making: alternative-focused and value-focused. In alternative-focused decision-making, alternatives are created, and then values for evaluation are considered.R. Keeney (1994) argues that alternatives are only relevant as means to achieve values. Therefore, R. L. Keeney (1996) introduces value-focused decision-making, where values are identified first and then multiple alternatives are designed or considered based on those values.

Similar to R. Keeney (1994), in this thesis it is argued that the organization and structure of an aircraft parts tracking consortium present complex issues due to the inherent misalignment of stakeholders' unique values. Failure to account for such misalignment may result in unforeseen consequences, reduced stakeholder involvement, compromised long-term survival or even fraud. From a design standpoint, it is assumed that the establishment of consortium governance mechanisms, such as decision rights or access rights, is based on interaction among stakeholders rather than being set exogenously by tradition. It is argued that an effective consortium design requires a careful balance of potentially opposing values and interests (Di Fonzo & Russo, 2015). This section addresses the values that have been identified in the literature by the usage of traditional technology adoption models. The values determined in this section serve as the foundational basis for the governance designs explored in the subsequent chapters. These values, derived from a comprehensive analysis of stakeholder interactions and technological capabilities, provide critical insights into the priorities and concerns that must be addressed in the governance designs.

3.3.1. Literature Used

This section makes substantial use of literature to back up the stakeholder values presented in **Table 3.3** and **Table 3.4**. This subsection describes the search technique and the generated literature. **Table 3.2** displays the search keywords used in the Scopus search engine, the number of results, and the number of publications judged relevant to this research. The total number includes duplicate publications, for that reason it is important to say that finally a total of 17 papers are evaluated. A full list of the papers with their citations can be found in **Appendix D Table D.1**

Table 3.2: Scopus Search Results

Search Term	Refined By	Results (N)	Relevant (N)
Blockchain AND Consortium	Language: English Relevant Field: Business Management Years: 2020 - 2024	115	14
Blockchain AND Consortium AND Stakeholders	Language: English Relevant Field:Business Management Criteria: Relevant Title and Abstract	14	7
Blockchain AND Consortium AND Values	Language: English Criteria: Relevant Title and Abstract	11	3
Blockchain AND Consortium AND Stakeholder Values	Language: English Criteria: Relevant Title and Abstract	5	1
Blockchain AND Consortium AND Stakeholder Values AND Aviation	-	0	0

3.3.2. Results

The existing literature has uncovered a lack of research regarding ”the values of a consortium”. Taking this into account, thorough research is conducted to understand the values of each individual stakeholder implementing blockchain technology and joining a consortium. A comprehensive review of seventeen papers has been conducted to investigate stakeholder values regarding blockchain technology, with a specific emphasis on supply chain traceability. These papers encompass various industries, ranging from the healthcare supply chain to agriculture, thereby offering a wide range of perspectives. Among the papers, the Technology, Organizational, Environmental (TOE) framework emerged as the most frequently employed model in this body of research (Ghode et al., 2020; Kouhizadeh et al., 2021a; Orji et al., 2020; Silva & Mattos, 2019; Wang et al., 2019).

To begin, within the context of technology, stakeholders have underscored several key values, including privacy, security, understandability, compatibility, efficiency, and ease of use, as seen in **Table 3.3** with their linked sources. Privacy and integrity are primarily concerned with data-related issues. Stakeholders are particularly attentive to who can access their data, the security measures in place to protect it, and how seamlessly data can be transferred between systems (Ghode et al., 2020; Orji et al., 2020; van Hoek, 2019). On the other hand, the values of security compatibility, understandability, and ease of use pertain to the practical usability of the technology itself (Alharthi et al., 2020; Orji et al., 2020; Saberi et al., 2018; Silva & Mattos, 2019; van Hoek, 2019; Wong et al., 2020; Yadav et al., 2020). Stakeholders are interested in how easily they can comprehend the new technology, the efficiency gains it promises, and how user-friendly it is. These values are crucial as they determine how smoothly stakeholders can integrate the technology into their operations and adapt to new workflows.

Table 3.3: Technology Values

Technology Values	
Values	**Sources**
Privacy	(Ghode et al., 2020), (van Hoek, 2019) , (Orji et al., 2020), (Dong, 2024)
Security	(Silva & Mattos, 2019), (Saberi et al., 2018), (van Hoek, 2019) , (Chittipaka et al., 2023), (Sanghoon Shin & Abouarghoub, 2023)
Understandability	(Alharthi et al., 2020), (Wong et al., 2020)
Compatibility	(Alharthi et al., 2020), (Wong et al., 2020), (Yadav et al., 2020), (Chittipaka et al., 2023)
Ease of Use	(Alharthi et al., 2020), (Wong et al., 2020), (Yadav et al., 2020), (Orji et al., 2020), (Dong, 2024)
Sustainability	(Wang et al., 2019)
Integrity	(Ghode et al., 2020)

To continue, within the organizational context, researchers have identified seven key values, as illustrated in **Table 3.4**. Among these, trust and awareness of the need for data sharing are highlighted as decisive when interacting with other stakeholders (Anjum, 2019; Ghode et al., 2020; Kouhizadeh et al., 2021a; Orji et al., 2020; Saurabh & Dey, 2021; Silva & Mattos, 2019; Walker et al., 2016; Wang et al., 2019). Trust ensures that stakeholders can confidently share information, while awareness of data-sharing needs promotes collaborative efforts and efficient communication. Additionally, stakeholders have emphasized the importance of authority oversight. Effective oversight is necessary to facilitate rules and regulations, ensuring that blockchain adoption adheres to industry standards. Social acceptance and sustainability are also regarded as significant values. Social acceptance refers to the broader acceptance of blockchain technology by all stakeholders, which is essential for its successful implementation. Sustainability, on the other hand, pertains to the long-term viability and environmental impact of the technology, which stakeholders view as critical for the broader good during the adoption process. Finally, stakeholders recognize that blockchain technology holds substantial value only when adopted by a diverse and extensive array of participants. This recognition underscores the importance of growth and widespread implementation. The more participants that adopt the technology, the more effective and beneficial it becomes, creating a network effect that enhances its overall utility and impact.

Table 3.4: Organizational Values

Organizational Values	
Values	**Source**
Awareness	(Silva & Mattos, 2019) , (Kouhizadeh et al., 2021a), (Dong, 2024)
Trust	(Ghode et al., 2020), (Saurabh & Dey, 2021), (Wang et al., 2019), (Chittipaka et al., 2023), (Sanghoon Shin & Abouarghoub, 2023)
Social Acceptance	(Ghode et al., 2020), (Kouhizadeh et al., 2021b), (Orji et al., 2020)
Growth	(Silva & Mattos, 2019), (Yadav et al., 2020), (Kouhizadeh et al., 2021b)
Authority Oversight	(Saberi et al., 2018), (Alharthi et al., 2020), (Silva & Mattos, 2019)
Internal Support	(Walker et al., 2016), (Anjum, 2019), (Wang et al., 2019)

Nevertheless, some researchers who have contributed to the identification of the values that are mentioned in these tables have critiqued the TOE framework for its limitations. One significant limitation is its static nature, as it does not account for changes over time, which can be decisive in dynamic environments where technology and organizational needs evolve (Kuan & Chau, 2001). Additionally, Johnson and Garza (2015) argue that the TOE framework may not sufficiently address the role of human factors and their interrelationships, which are often critical to the successful implementation and adoption of new technologies. Human factors, including user relations, skills, and the overall culture, can significantly influence the effectiveness of technological adoption. Furthermore, the TOE framework primarily focuses on the initial adoption phase of technology and tends to overlook the post-adoption phase. This oversight includes the actual usage and integration of the technology into organizational processes, which are essential for realizing the full benefits of the technology (Awa & Ojiabo, 2016). In addition, Saberi et al. (2018) expanded the TOE framework by subdividing organizational context into inter-organizational and intra-organizational categories. This nuanced categorization provides a more detailed understanding of how organizational dynamics at different levels influence blockchain adoption. Further extending the analytical approach, Yadav et al. (2020) utilized the ISM-DEMATEL method to examine the interrelationships among the contexts. This method recognizes that contexts are not isolated but are interconnected, necessitating a comprehensive approach to address them effectively.

Collectively, these studies highlight the limitations of the TOE framework and emphasize the necessity of understanding the values stakeholders hold in the adoption of blockchain for part tracking. Despite efforts by researchers and industry players to incorporate these values into consortium governance based on existing literature, the formation of consortia remains limited. Due to these reasons, this research will delve deeper into the technological and organizational contexts of the TOE framework by exploring a real-world consortium. The organizational context is expanded in scope to include inter-organizational aspects, as suggested by Saberi et al. (2018). This broader approach ensures that the interactions and relationships between different organizations are thoroughly examined. This context is named as stakeholder context for the remainder of the thesis.

Furthermore, aligning with the perspective of Yadav et al. (2020), and to prohibit the main weakness of the TOE framework which is overlooking specific factors, an additional context namely 'data', is investigated in detail. The rationale for investigating data separately from the technology context is multifaceted. Primarily, data is regarded as a fundamental resource for any company, making its importance critical. While the technology context focuses on the characteristics and functionalities of blockchain itself such as scalability, security, and interoperability the data context covers a broader array of issues related to data governance. These issues include data ownership, confidentiality, and integrity. By isolating the data context, the research allows for a more nuanced and detailed analysis of these specific concerns, ensuring that the governance mechanisms address the unique values associated with data. Moreover, this distinction is supported by recent studies that underscore the increasing significance of data governance in digital transformation and innovation frameworks (Zhong & Moon, 2023). These studies highlight the necessity for tailored strategies to effectively manage data in collaborative environments.

This detailed examination addresses the gap in understanding how data considerations influence technology adoption within a consortium. To summarize the framework evolved from the Technology Organization Environment (TOE) model to a Blockchain Stakeholder Data (BSD) framework. This new framework reorients the focus towards blockchain aspects, stakeholder interactions, and the data context to investigate values in part tracking consortium. To contribute to the literature with the above-mentioned methodologies, an initiative for a part-tracking consortium involving all stakeholders is approached and the results identified and derived from practice are explained in **section 3.4**.

3.4. Stakeholder Values in Practice

3.4.1. Participatory Observation

Throughout the thesis, the researcher played a dual function inside the various work groups of IDCA, acting as both an observer and a secretary during the two days when several stakeholders were physically present in the Netherlands. This participatory observation provided valuable insights into the complexities of consortium formation processes in the aviation industry. Simultaneously, playing the role of the secretary helped the researcher with the documentation of key points, further action points, and the precise recording of five workgroup meetings. This comprehensive engagement facilitated not only observation for the researcher but also active participation in discussions.

3.4.2. Results of Participatory Observation

During the different workgroup meetings, three key stakeholder values that are not mentioned by literature have emerged: **Tangibility of Technology, Data Ownership, and Legitimacy**.

- **Tangibility of Technology**
  Tangibility of technology emphasizes the significance of demonstrating the practical applicability of the platform with real-life data and implementation to gain attention and increase participation. During discussions, stakeholders belonging to different groups in the aviation industry have stated that discussions that are based on a hypothetical scenario are hard for them to grasp and prohibit them from convincing others to join such a data-sharing environment.
- **Data Ownership**
  Over the course of two days and multiple meetings, stakeholders have emphasized their perception of data as the most valuable asset within their company. They highlight its significance in process improvement and security enhancement. However, stakeholders also acknowledge that ownership of data remains ambiguous, serving as one of the major barriers to sharing it and they recognise it as a pivotal factor for determining the next steps. Because of its importance to the stakeholders, the data context is added to the framework.
- **Legitimacy**
  The value of legitimacy in this context refers to the inclusion of authorities from the aviation industry within the consortium. While legitimacy or legitimate means allowed by law [1], rather than something acceptable stakeholders specifically articulated this value as "legitimacy" during meetings denoting the presence of legal authorities (IATA, EASA) within the consortium essential for acceptance, unintentionally implying that absence would render the endeavour unlawful or unacceptable. The primary reason for emphasizing legitimacy is to enhance the consortium's credibility. The involvement of legal authorities would signify that the initiative is not merely experimental, but a serious and committed effort within the industry rules and regulations.

It is assumed that by developing consortium governance mechanisms based on the identified values, stakeholder participation and the long-term viability of a part-tracking consortium can be achieved. To uncover additional stakeholder values and gain a deeper understanding of their implications, additional interviews were conducted.

3.4.3. Interviews

The purpose of conducting interviews was to identify what stakeholders value through discussions of past experiences and future needs and wants for participating in a data-sharing consortium. This aims to ensure that these values are accurately understood and incorporated into effective governance mechanisms for blockchain adoption in the aviation part-tracking consortium. To ensure full representation of each stakeholder group throughout the lifecycle of an aircraft part, one high-level executive individual from each stakeholder group as identified in **Table 2.3** has been conducted.

3.4.4. Interview Structure

For this research, a semi-structured 45-minute interview approach is deemed appropriate to facilitate in-depth data collection and a comprehensive understanding of stakeholder values, aligning with the guidelines of Sekaran (2016). This approach involves conducting one-on-one discussions, allowing for detailed and personalized insights into each stakeholder's perspectives. Considering that individuals may not explicitly articulate their values, an indirect approach is taken where values are asked implicitly through discussing past experiences and future needs and wants.

The interview starts with delving into the present circumstances and responsibilities of the participant. This introductory step aims to streamline the explanation process by providing a familiar starting point. By addressing the current situation and tasks, participants find it easier to articulate their thoughts. Moreover, this approach serves as an effective icebreaker, fostering a comfortable atmosphere for open dialogue. Finally, it offers valuable insights to the interviewer,

[1] https://dictionary.cambridge.org/dictionary/english/legitimate

validating the interviewee's stakeholder group.

Following the discussion on the present way of working regarding the data sharing initiative for part tracking, the interview proceeds to ask about the interviewee's past involvement regarding data sharing among different stakeholders in the aviation industry. This phase serves dual purposes. Firstly, it begins channelling the ideation of the interviewee towards the direction the interview will take, setting the stage for deeper exploration. Secondly, it facilitates reflection on past experiences, which serve as benchmarks for expressing future needs and desires which will be the subsequent step in the interview process. During this phase, the primary objective is to gain a comprehensive understanding of stakeholder values within the BSD framework. During this phase, stakeholders are requested to elaborate on their past experiences from their own perspectives. Furthermore, they are encouraged to adopt the perspectives of other stakeholders by being asked ”You have mentioned project X, during the project what governance arrangements did other stakeholders debate the most about and why?”, thereby gaining a comprehensive understanding of multiple viewpoints. This approach aims to foster empathy and a holistic understanding of the challenges faced by all parties involved. Furthermore, the interview seeks to understand technology interaction values. This entails examining how stakeholders perceive and engage with blockchain. The reason for examining technology value is that humans have varying priorities when interacting with different types of new technology. For instance, humans might prioritize data privacy while engaging with AI, however, while interacting with a self-driving car safety will be emphasized more rather than data privacy.

In the final phase of the interview, stakeholders transition from reflecting on past experiences to envisioning future needs and desires. This shift in perspective aims to directly extract critical values essential for moving forward. The interview concludes with a validation step, where the interviewer ensures that he has accurately understood the implicit values expressed by the stakeholders. Additionally, stakeholders are invited to propose strategies for incorporating all identified values effectively. This question serves a dual purpose: it encourages stakeholders to reflect on the feasibility and viability of their expectations while also fostering a collaborative brainstorming session to explore innovative solutions. Finally, stakeholders are given the opportunity to share any additional thoughts or insights they may have, providing a comprehensive overview of their perspectives and priorities. A complete list of all interview questions can be found in Appendix B Figure B.1 and Figure B.2.

Moreover, in addition to the interview process, several preliminary steps are taken to assist the interview candidates. Interviewees are provided with a pre-interview guide. This guide ensures that the terms used during the interview carry consistent definitions and avoid any ambiguity. This guide is distributed to interviewees via email ahead of the interview session, and it is also reread by the interviewer to the candidates before the interview commences to confirm alignment and ensure the guide has been reviewed. The pre-interview guide can be found in Appendix B Figure B.3

If interviewees still have uncertainties about the definitions, further clarification is provided on the topics by elaborating on three public examples of blockchain governance arrangements and their associated values. These values are identified through scholarly research and are presented to the interviewees as in Appendix B Figure B.2. Finally, the interviewees are presented with the consent form shown in Appendix B Figure B.4 to ensure full compliance with the aforementioned HREC regulations.

3.4.5. Interview Participants

8 high-level executives collectively covering the entire supply chain in aircraft parts consented to be interviewed between May 2024 and June 2024. It is important to note that the list of interviewees is purposefully left out. This collection includes essential information about their distinct positions and their past experiences in blockchain implementation initiatives. The decision to remove this material is based on Potentially Identifiable Research Data (PIRD) which could lead to the identification of the interview candidates. Access to this list is solely limited to TU Delft supervisors.

A non-probability sampling method is used to select the participants, specifically, judgment sampling (Sekaran, 2016) since the people that are selected are experts and have hands-on experience on this topic. The participants' expertise revolves around the usage of blockchain data consortiums for part tracking in the aviation industry. One could argue that this judgmental sampling method may have introduced an unintended positive bias since participants have had some prior involvement with blockchain technology. Efforts are made to mitigate this positive bias by specifically inquiring, ”What aspect of blockchain technology makes you most uncomfortable during implementation or usage, and why?” This critical perspective is intended to address potential positive biases, although its effectiveness remains open to discussion. Further discussion on this matter will be included in the limitations section of the thesis. Yet another important aspect of the interviews is the inability to interview the specific stakeholder group of Regulators. Despite multiple attempts made through email and personal contacts, they were unable to allocate time due to their limited capacity. As an alternative, an independent aviation consultant with a diverse background and over 30 years of experience is interviewed to provide a general overview of the industry.

3.4.6. Interview Analysis

The data gathered from the interviews were analyzed using thematic content analysis which enables the identification of themes in the data. Themes represent patterns or meaningful responses in the data that are pertinent to the research questions (Braun & Clarke, 2006). This analysis followed the 4-step process outlined by Braun and Clarke (2006): transcribing the interviews, familiarizing with the data, generating initial codes based on participants' responses and grouping similar text units to form provisional themes. Since these text units could belong to multiple themes, they are carefully reviewed to ensure they comprehensively represent the data within each one and are aligned with their respective definitions. Finally, the value creation is based on the generated themes. The coding process of the interviews is conducted in one cycle due to the limited number of researchers. This comprehensive approach enabled the identification and extraction of meaningful themes within the constraints of the available time and resources. By doing so, the research is able to address its objectives effectively, ensuring that the relevant values influencing blockchain adoption in the aviation part tracking consortium are thoroughly examined and understood.

3.5. Interview Results

This subsection specifically addresses the stakeholder values derived from one-on-one interviews. The results are discussed in three phases, in line with the created tables that can be seen in **Figure 3.1**, **Figure 3.2** and **Figure 3.3**, which demonstrate a quote from the interviews, the generated first-order code, and second-order code to provide a comprehensive understanding of the various value dimensions of stakeholders identified during the interviews. In the three subsections **subsection 3.5.1**, **subsection 3.5.3**, **subsection 3.5.2** each second-order code is described, explaining its significance for the stakeholders along with its definition. Following this, the first-order codes and their definitions are introduced.

First, the discussion focuses on stakeholder context in **subsection 3.5.1** and the identified values are summarized in **Figure 3.1**. This figure and section provide insights into the values stakeholders hold regarding their interactions with companies, detailing what matters to them in these relationships and what they expect from other stakeholders. Understanding these interaction values is crucial for fostering effective collaboration and ensuring that the governance arrangements align with the collective expectations and needs of all involved parties.

Following this, consistent with the Blockchain Stakeholder Data (BSD) framework, blockchain technology is summarized in **Figure 3.2**. **subsection 3.5.2** explore stakeholders' values related to the adoption of blockchain. By examining these technological values, the study aims to identify critical values that can influence the successful adoption and integration of blockchain technology in an aviation part-tracking consortium.

Finally, the interviews revealed a significant focus on the importance of data for companies, which is discussed in **subsection 3.5.3**. Beyond the values stakeholders held among themselves and the technology they intended to use, discussions frequently revolved around data-related concerns. Recognizing the importance of data in the blockchain context, **Figure 3.3** demonstrates the values stakeholders have concerning their data. This includes their concerns and expectations about data control, confidentiality, and access within the blockchain ecosystem. The coverage of the identified values is expected to increase the formation of data-sharing relationships within the aviation ecosystem.

3.5.1. Stakeholder Context & Values

Understanding the stakeholder context and the discussed values is critical for successful cooperation, communication, and goal alignment inside consortiums. Consortium members may develop harmonious working relationships, avoid disputes, and improve communication channels by understanding each others' beliefs, expectations, and values. Tailoring strategies and governance arrangements according to these values can increase stakeholder satisfaction, trust, and involvement, resulting in more effective efforts. The values identified through interviews are summarized in alphabetical order, with their corresponding first-order code and one example stakeholder quote from the interviews in **Figure 3.1**.

- **Awareness**
  Awareness is defined as understanding the need and benefit of sharing data at present based on current inefficiencies among aviation part-tracking stakeholders. This value is perceived under two first-order codes. Stakeholders hold the belief that all parties need to recognize that sharing data will lead to beneficial results for each individual stakeholder's key performance indicators (KPIs). Currently, organizations maximize their KPIs using their own data, but the potential for even further improvement lies in accessing data beyond their immediate purview. Secondly, and more importantly, there is a critical need to share data, primarily driven by safety concerns that impact the entire industry. For example, sharing data can help counter widespread rumours about 'fake parts,' thereby making the industry safer and providing significant benefits.
- **Benefit Equality**
  Another value derived from stakeholder interviews is benefit equality, which entails that all involved stakeholders receive equal benefits in monetary terms or KPIs. Within the fiercely competitive domain of the

Quote	First Order Code	Second Order Code
"Being able to improve some of the key performance metrics that we all have, specific to our organizations, the only way to get more improvement is essentially to be able to consume information that exists outside of our organizations"	Data Sharing Benefit Awarness	**Awareness**
"So we have a mutually inclusive mutual incentive type of a construct to be able to proceed with data-sharing projects because the information that we are going to share is going to help the overall industry in safety enhancements"	Data Sharing Need Awarness	
"If there's one party that is excessively receiving monetary compensation compared to others, then that's immediately a reason why you want to quit the consortium and say why am I contributing and somebody else is benefiting? So fairness of the value distribution is, I think, a very important aspect that companies will put forward."	Fair Value Distribution	**Benefit Equality**
"A quitting reason for a stakeholder from the consortium is just anything they are going to perceive that someone else is going to get a competitive edge out of seeing anything."	Gaining Competitive Advantage	
"... if we agree together as a consortium on some rules and someone is not paying attention to these rules and violating the rules would make us quite the consortium. So I think that is one mandatory aspect that if there are rules set in place with everyone approval nobody should violate or should be able to violate these rules."	Adhering to the Rules of the Consortium	**Compliance**
"[...] it's my hope that more people, uh, you know, across those various different organizations feel comfortable to adopt the technology because the more people that adopt the technology or adopt the construct, the more valuable it becomes for others because it's really more of a network type of play. The more people that participate, the greater the value for all."	Network Effect	**Growth**
"I think what is important to also take into account. What makes companies join such a consortium, and how to grow those consortiums? Especially in our case, we want to have a good set of companies from the entire industry. Uh to have a good representation and give everyone a voice and I think that if you look now at the participants that there are a lot of OEM's, some Mros which is not the optimal situation"	Stakeholder Representation	
"I do think that regulators and authorities should be involved in such a consortium. Authorities work outside the commercial arena in the sense that the regulations are for the societal good, for the good of society, not necessarily the good of individual players.In this, in this ecosystem, so anything we do, any regulations we put forward or any consensus has to be compatible with the regulations."	Involvement of Authorities	**Legitimacy**
"For example, if I just talk about mobility and the implementation of new technologies in it. However, implementations and adoptions are less popular in the aerospace world, and partly that is because of the safety regulations and data regulations that are associated with which we have to make sure we comply with.."	Involvement of Regulations	
"The consortium (such as IDCA) would play this role of trying to harmonize or have a kind of a universal rule of the road, you know, and in terms of being able to understand, you know, a stop sign, a yield sign, a, you know, speed limits, et cetera, being able to have something that we can generally agree on would be kind of, you know, international rules of the road."	Legislative Neutrality	**Neutrality**
"We (operators) know that if we execute the rules, nobody will join. And if a third-party platform provider will dictate the rules. Then nobody would join either!"	Executive Neutrality	
"We've got a bad actor out there that's saying Nope. I don't want anybody to see any of this stuff, but I want to see it all then and that's what we would hope that the consortium would be a part of is that someone would, you know, be able to say, raise their hand and say, hey, I can't see what I was supposed to see.And you know company XYZ is blocking everything and they would have to be there to apply arbitration for that."	Arbitrage Neutrality	
"I think the idea was to talk to customers where we have good relationship to and get their feedback on this (creation of data sharing consortium) and get behind what their view on this would be. And if that is maybe acceptable for them or not."	Initiation of Trust Clusters	**Trust**

Figure 3.1: Stakeholder Interaction Values

aviation sector, where profit margins are notoriously narrow, stakeholders approach data sharing with caution due to the possibility of compromising their competitive edge. In this regard, two first-order codes regarding benefit equality are identified: First, Fair Value Distribution, which entails that any monetary or non-monetary value generated by the totality of stakeholders should be distributed equally among them. Secondly, Gaining Unequal Competitive Advantage refers to the ability of stakeholders to use shared data against the original data sharer in a manner that the original sharing stakeholder could not have anticipated.

- **Compliance**
  Another significant value highlighted during the interviews was the emphasis on compliance. In this context, compliance pertains to following the rules and agreements established by the consortium itself for its stakeholders to follow. This commitment ensures that all stakeholders involved in collaborative efforts within the blockchain operate within the boundaries of agreed-upon standards, protocols, and legal requirements. Compliance fosters effective collaboration and enhances the consortium's reputation while mitigating risks and prohibiting any disputes.
- **Growth**
  The value of growth within the consortium refers to the overall increase in stakeholders joining the initiative. This value consists of two primary components: network effects and representation. The network effect underscores the importance of expanding participation in the consortium. It acknowledges that as more stakeholders join, the value and benefits of collaboration increase. However, stakeholders exercise caution in this regard, which leads to the second first-order code, namely representation. Stakeholders emphasize that new members should reflect the diversity of the entire industry rather than favouring specific entities. This approach ensures that there is broad representation within the consortium, encompassing a wide range over a part lifecycle as well as different perspectives, expertise, and interests. Additionally, diverse representation ensures that all voices are heard and considered in decision-making processes. This not only strengthens the consortium's resilience but also enhances its credibility within the industry.
- **Legitimacy**
  In addition to being observed during participatory observations, the concept of legitimacy continues to emerge as a recurring theme in stakeholder interviews. Upon analysis, the definition of legitimacy is broadened, and two distinct first-order codes of 'legitimacy' are identified as the 'involvement of authorities' and the 'involvement of regulations'. The involvement of authorities refers to the participation of relevant governmental bodies and authorities in the consortium's activities. Stakeholders place importance on obtaining official support to enhance the credibility of their collaborative efforts. Legitimacy was placed under the stakeholder context as it involves the direct integration of authorities and regulatory bodies as internal stakeholders, which could significantly influence communication, internal governance and decision-making processes. Similarly, the involvement of regulations is crucial, encompassing adherence to industry-specific guidelines and standards as well as compliance with broader data regulations.
- **Neutrality**
  The value of neutrality emerged as a complex and contradictory aspect during stakeholder discussions. Despite the commitment to decentralize data management, stakeholders expressed a need for centralized, neutral entities to fulfil legislative, executive, and arbitrage functions, indicating the traditional separation of powers. They highlighted the necessity of a neutral body ensuring equitable formulation of consortium data-sharing rules and standards for legislation. Additionally, stakeholders identified the need for a centralized, neutral entity in the executive domain to oversee implementation. Finally, they emphasized the importance of an unbiased arbitrage mechanism in resolving conflicts within the consortium, facilitating fair and transparent dispute resolution processes.
- **Trust**
  Trust is a fundamental value that initiates data sharing and fosters consortium participation. When stakeholders have a history of collaboration with the companies involved and believe they can depend on them, they are naturally more inclined to engage in these initiatives. This trust acts as a powerful bond, encouraging active involvement and cooperation within the consortium, thereby facilitating the exchange of valuable information and driving collective progress.

3.5.2. Blockchain Context & Values

Investigating and understanding technology-specific values is key for successful blockchain implementation. Each technology comes with its own set of values, characteristics, and considerations that are essential for its effective adoption and integration. It is important to recognize that these values are not uniform across different technologies and cannot be unified. The values identified through interviews are summarized in alphabetical order, with their corresponding first-order code and one example stakeholder quote from the interviews in **Figure 3.2**

Quote	First Order Code	Second Order Code
"We should also take into account alliance changes in the consortium. So we (service providers) have to be nimble enough to adjust for that as well."	Adjust to Change	**Adaptability**
"You are trying to build this history of the life cycle, and if you can't link new blockchain (databse) with the already existing database together properly, then what good is it?"	Integration of Databases	**Compatibility**
"Sustainability is a problem where if you put all the data on the chain, then the chain will get humongous. So it's and it will produce too much CO2 or it will consume too much energy."	Environmental Sustainability of Technology	**Sustainability**
"I think you need to be able to, come up with models beforehand because ultimately you have to execute them and see how it actually works. For convincing the community, you have to come up with maybe some simulations on scenarios on how you know a particular stakeholder is putting information on the blockchain and on the other side, when this information is being used, being rewarded."	Implementation of Technology	**Tangebility**
"Sometimes participating people had really issues to understand because I think it has to do a little bit with the complexity of blockchain from my perspective. Yeah, it's not so easy to understand as a central database where you have a server Oracle server where you have a database on it and you have certain tables and you have a clear access model for the data. And I think that's much much easier to understand and I think it's a bit regarding the complexity that everybody does not understand."	Understandability of Technology	**Understandability**

Figure 3.2: Blockchain Interaction Values

- **Adaptability**
  The value of 'adaptability' underscores stakeholders' perspective on consortium participation as a dynamic and evolving process rather than a static arrangement. Stakeholders recognize that the consortium's evolution and dynamics, including changes in membership alliances, highlight the importance of having a flexible technical architecture capable of adapting to such membership transitions.
- **Compatibility**
  Interviewees, particularly those who have advanced from proof of concept to implementation, have emphasized the significance of database compatibility. They stress the need to integrate new data with existing datasets during updates to ensure the establishment of a sustainable blockchain ecosystem.
- **Sustainability**
  During interviews, environmental sustainability emerged as a significant value, highlighting its utmost importance in today's aviation industry. Stakeholders in the aviation sector are actively striving to mitigate greenhouse gas emissions through innovative measures, such as exploring alternative fuel sources. However, as these transitions take time, there is a pressing need to incorporate environmentally friendly practices across all operational aspects. Concerns arise regarding the adoption of blockchain technology, as the processing of vast amounts of data is anticipated to require substantial energy, potentially resulting in increased emissions. Therefore, prioritizing environmental considerations is key during decision-making processes concerning blockchain adoption in the industry.
- **Tangibility**
  In addition to being observed during participatory observations, the tangibility of technology also came up frequently in interviews regarding the adoption of blockchain technology in part tracking. Through the analysis, a specific aspect of 'tangibility' is identified: implementation. Implementation relates to how the technology is applied in real life, including how it looks, how it helps users, and what outputs it produces. This value emphasizes the significance of demonstrating the platform's practical applicability with real-life data and implementation to gain attention and increase participation.
- **Understandability**
  Understandability underscores the necessity for individuals to fully comprehend the systems they are utilizing to ensure successful adoption. This sentiment is encapsulated in the observation that participants frequently encountered difficulties in understanding, primarily due to the inherent complexity of blockchain technology. Blockchain presents a more challenging conceptual framework, unlike traditional centralized databases, such as an Oracle server. This complexity can impede user adoption, as the decentralized nature and intricate mechanisms of blockchain demand a more profound level of understanding compared to conventional systems. Consequently, it is imperative to ensure that users can grasp the fundamental concepts of blockchain to facilitate its widespread acceptance and effective implementation.

3.5.3. Data Context & Values

The justification for studying data independently of the blockchain context is multifaceted. In today's dynamic business environment, data has become indispensable, offering companies numerous advantages, including gaining a competitive edge, mitigating risks, enhancing customer service, and refining marketing strategies through precise targeting. Moreover, data-driven processes significantly boost efficiency and contribute to cost reduction across operational functions (Tkalych, 2024). While the blockchain context emphasizes the properties and functionality of blockchain, the data context addresses a broader spectrum of data governance challenges. By isolating the data context, the study facilitates a more nuanced and comprehensive examination of the values that governance mechanisms effectively need to address. This distinction is further reinforced by recent research highlighting the increasing importance of data governance within digital transformation and innovation frameworks (Zhong & Moon, 2023). The values identified through interviews are summarized in alphabetical order, with their corresponding first-order code and one example stakeholder quote from the interviews in **Figure 3.3**

Quote	First Order Code	Second Order Code
"I'm not quite sure, about what would make me quit the consortium other than the ability to, you know, have a system where we cannot, somehow control our data regarding who sees it or who uses it for example."	Controlling the Data that you Provide on the Blockchain	**Access Control**
"Well, I guess I can say one thing. I mean consistently and we've stayed away from this, no financials, we want nothing to do with. I don't care how much you bought or sold that part or how much it costs you to do the repair. How much did the pieces go? So we'll stay 100% away from the financials because That's always the number one concern I don't want to share my pricing with anybody."	Financial Confidentiality	**Confidentiality**
"Taking advantage of our intellectual property in how we are planning our material pool, for example, this is definitely I think something which needs to be addressed and avoided."	IP Confidentiality	
"Obviously changes in data ownership would make us quit the consortium."	Data Ownership	**Ownership**

Figure 3.3: Data Interaction Values

- **Accessibility Control**
  When transferring data across consortium members or committing it to blockchain, access control poses a conundrum. Although sharing requires some transparency and a certain amount of control to be given up, data is still a very valuable resource for businesses today. Therefore, stakeholders are anxious to make sure that the data stays inaccessible to parties they do not know, or they do not want to share. This value has been referenced in several interviews, particularly emphasizing direct competitors' accessibility as a critical factor and mentioning that it is a clear deal-breaker as well as a reason for exiting the consortium.
- **Confidentiality**
  Confidentiality means the state of keeping or being kept secret or private. Interviewees translate this as protecting any financial data and intellectual property that could be derived from data sharing, which emerged as a critical value among stakeholders. Stakeholders expressed a firm point of view on financial confidentiality, avoiding the sharing of any financial data, citing concerns about sharing pricing information or transaction details. Additionally, stakeholders underscored the significance of preserving confidentiality regarding technical data or intellectual property (IP), acknowledging stakeholders' withdrawal from sharing information. The interviewees stated that confidentiality is one of the critical values that would lead to multiple iterations when implementing such a data-sharing consortium. Intellectual property is considered within the data context because it focuses on the practical aspects of securing and managing technical data and proprietary innovations rather than broader external factors such as regulatory requirements and industry norms.
- **Data Ownership**
  Data ownership, particularly with the rise of artificial intelligence, has emerged as one of the most discussed topics. Just like in the participatory observations, it also emerged as a critical value during interviews. Stakeholders articulated concerns regarding changes in data ownership, acknowledging its potential to influence the consortium's dynamics profoundly. This sentiment is expressed when they were asked, "What boundary being crossed would actually make you quit the consortium?" One of the stakeholders responded: "Obviously, changes in data ownership would make us quite the consortium" If this value is not upheld in both directions, they will promptly withdraw from the consortium.

3.5.4. Stakeholder Quote Analysis

The main contributing method, which was a series of 45-minute semi-structured interviews, was conducted with eight high-level executives, collectively covering the entire supply chain in aircraft parts. The three most frequently mentioned values were technology tangibility, neutrality, and data access control. 20 specific quotes from the 8 interviews were identified regarding accessibility control, 14 for neutrality, and 14 for tangibility of technology.

Discussions about accessibility control revealed that 7 out of 8 participants (88%) cited control over data as their primary reason for hesitating to fully commit to blockchain solutions. Half of the participants (50%) are concerned about competitors accessing their data, while the remaining participants are worried about data privacy and the immutability of the blockchain. Additionally, participants highlighted the need for a neutral and independent consortium to manage the blockchain. Six out of eight participants (75%) stated that an effective consortium should ensure fair rule-making and provide arbitration in case of disputes, emphasizing the importance of arbitration and legislative neutrality. Additionally, 2 out of 8 participants (25%) mentioned past negative experiences with single-entity governance models, which led to distrust and reluctance to participate. Participants agreed that the consortium should include representatives from various sectors to ensure balanced decision-making. The third value focused on the tangibility of technology, which is mentioned in 14 quotes across the 8 interviews and observed during participatory observations. Participants expressed the need for concrete examples and demonstrations of how blockchain can be applied effectively in their specific industries. They emphasized that theoretical benefits alone are insufficient to convince them to adopt the technology.

3.6. Conclusion

In this chapter, the first sub-research question is answered.

What values do blockchain aviation part-tracking consortium stakeholders have?

An overview of the values that were identified through literature review, participatory observations and desk research is visualized as follows in **Figure 3.4**.

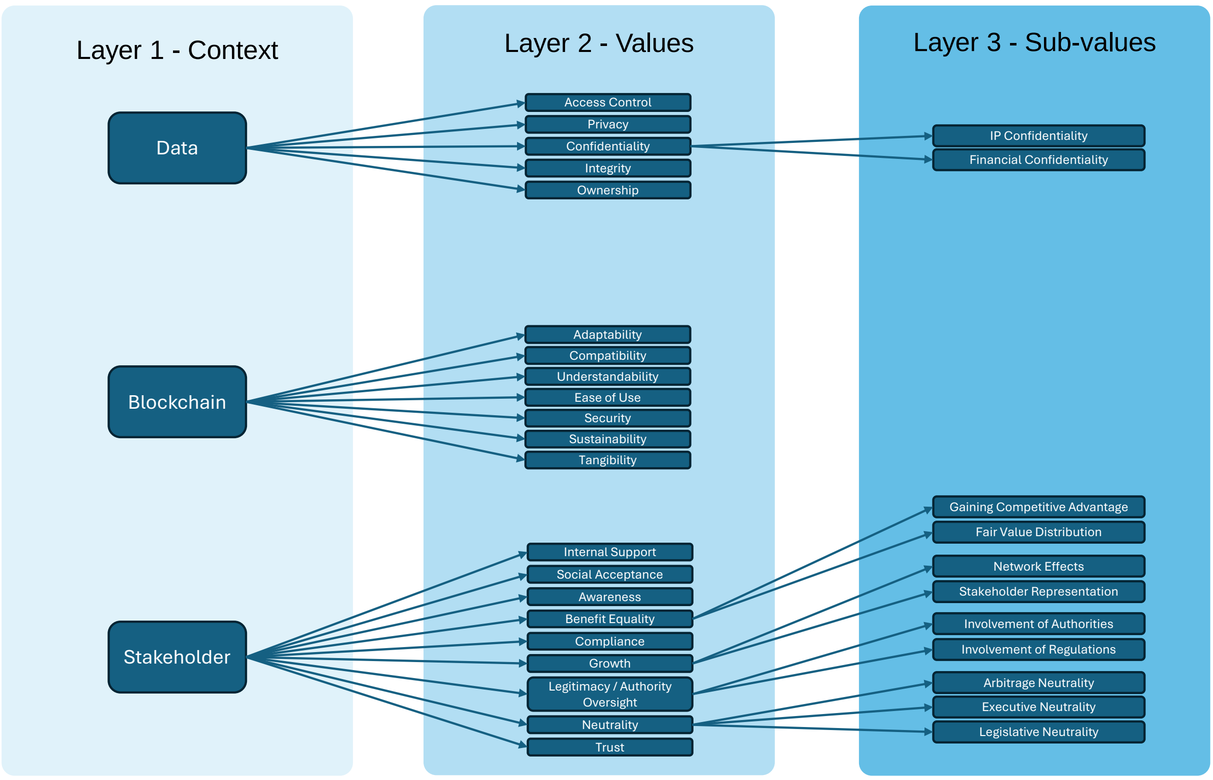


Figure 3.4: Value Layers 3 Sources Combined

Through various methods, 21 values and 11 sub-values have been identified. They are categorized under 3 contexts: data, blockchain, and stakeholder. While the blockchain context emphasizes the values regarding blockchain, the data context addresses a broader spectrum of data governance challenges. In today's dynamic business environment, data is indispensable, providing companies with competitive advantages, risk mitigation, and efficient operations. Isolating the data context from the blockchain context allows for a detailed examination of governance challenges, highlighting the growing importance of data governance in digital transformation and innovation. Finally, the stakeholder context encompasses both organizational and inter-organizational values within a consortium.

The categorization and explanation of these values serve as a foundational element for this study, ensuring that the governance designs are aligned with the values of stakeholders. These values provide a comprehensive framework for designing governance structures, as the objective of these designs is to fulfil these identified values. However, it is expected that addressing all these values simultaneously will be highly challenging. Additionally, it is anticipated that certain values will hold greater importance than others, necessitating a prioritization process. The quote analysis in **subsection 3.5.4** from the interviews does not directly indicate higher importance but rather suggests that it is easier for participants to conceptualize and explain. The next phase of the research involves a detailed analysis and ranking of these values, providing a clear roadmap for the governance design process. This ensures that the final governance framework is not only comprehensive but also pragmatic, capable of driving effective and sustainable blockchain implementation for part tracking in the aviation industry.

4 Stakeholder Value Weight Calculation

4.1. Introduction

The following chapter addresses the second sub-research question:

Sub-Research Question 2: What are the critical values of stakeholders for designing governance arrangements?

The second sub-research question is addressed by implementing a survey using the Bayesian Best-Worst Method. This chapter aims to establish a ranking among the identified stakeholder values and determine the most important ones for pragmatic design recommendations. The chapter starts with understanding the type of problem the research is addressing, as defined in **section 4.2**. Subsequently, a selection process among different methods to solve the multi-criteria decision-making problem is conducted in **section 4.3**, and an explanation of why the Bayesian Best Worst Method is chosen is elaborated upon. From **subsection 4.3.1**, the steps, application and mathematical calculations of the Bayesian Best Worst Method are detailed. Following this, the data collection process is examined, including the rationale for choosing a survey, as described in **subsection 4.4.1**. The design of the survey is then elaborated in **subsection 4.4.2** providing insights into the structure, content, and specific questions. Regarding the survey, further elaboration on the coding process in the specific software, Qualtrics, is described in **Appendix C section C.2**. The chapter continues with **subsection 4.5.1**, which addresses the sampling strategy used for selecting survey participants. This section explains the criteria for selecting respondents, the sampling method employed, and the characteristics of the sample population. The chapter is finalized in **section 4.6**, which not only highlights respondent overview and key findings but also discusses these implications for designing effective governance arrangements.

4.2. Multi-Criteria Decision Making Problem

To select the most appropriate method for addressing the second sub-question, it is crucial to understand the nature of the problem the research aims to solve. The primary objective of this research is to determine how stakeholders involved in the aviation industry, specifically benefiting from part tracking, can expand the number of participants to share data through blockchain over the entire lifecycle of an aircraft part. To achieve this, it is essential to identify the key values that different stakeholders consider important in a data-sharing consortium so that specific governance arrangement designs can fulfil these values.

However, governance arrangements and blockchain platform designs consist of multiple criteria that can be selected in various ways to fulfil the different values of stakeholders. Therefore, a method is needed to rank or assign weights to a set of values, allowing decision-makers to make better-informed decisions when constructing their data-sharing consortium. This research, consequently, addresses the Multi-Criteria Decision Making problem.

4.3. Multi-Criteria Weighting Method Selection

Multi-criteria decision-making (MCDM) is a widely utilized method across various domains, from portfolio management to the service industry, and it even extends to everyday decision-making (Rezaei, 2016; Saaty, 2004a). For instance, when purchasing a new bicycle, an individual may consider several criteria, such as price, seat comfort, weight, and gear availability. By evaluating these criteria, the individual can systematically compare different options and decide to select the most suitable bicycle. This approach ensures that all relevant values are considered, leading to a choice that best meets the individual's specific needs and preferences.

However, it is important to note that the criteria for purchasing a bicycle may not all carry the same weight. For example, if you are a student with a tight budget, you might prioritize cost over gear availability and opt for a cheaper model. Conversely, if you are elderly, seat comfort may be the most important criterion for you. To determine which criteria (or values in the case of an aviation part tracking consortium) are most important, there are two different weighting groups.

The first method is objective weighting. These methods derive weights from information gathered for each criterion using mathematical functions independent of the decision maker's preferences (Kao, 2010). Examples of objective weighting methods include entropy, mean weight, ideal point method, and Criteria Importance Through Inter-criteria Correlation (CRITIC) (Keshavarz-Ghorabaee et al., 2019; Wu et al., 2020; Yusop et al., 2015). Because these methods rely solely on mathematical computations, they require quantitative data. However, due to the limited access to real-world data for the researcher of this thesis, these objective weighting methods are not feasible and have been excluded from consideration.

The second method for weighting criteria is subjective weighting, derived from the preferences and inputs of decision-makers (Keshavarz-Ghorabaee et al., 2021). Surveys or interviews can be used to get input from decision-makers. However, both survey and interview design can vary depending on the chosen method.

Two commonly used subjective weighting methods are the Analytical Hierarchy Process (AHP) and VIKOR (Saaty, 2004b; Siregar et al., 2018). The AHP is an accurate approach to quantifying the weights of decision criteria, utilizing individual experts' experiences to estimate the relative importance of factors through pairwise comparisons. Respondents compare the relative importance of each pair of items using a specially designed survey. VIKOR, on the other hand, focuses on ranking and selecting from a set of alternatives, determining the compromise solution closest to the ideal solution.

However, these methods are often unfavourable due to the extensive number of comparisons required, specifically n(n-1)/2, to reach a reliable conclusion. To address this issue, a method requiring fewer comparisons is preferred, namely the Best-Worst Method. The BWM streamlines the process by reducing the number of comparisons needed to 2n-3 while still providing accurate and reliable weightings based on decision-makers preferences (Rezaei, 2015, 2016, 2020).

4.3.1. Bayesian Best Worst Method

BWM is a multi-criteria decision-making approach that utilizes two vectors of pairwise comparisons to determine the weights of criteria. Initially, the decision-maker identifies the best (most desirable or most important) criteria and then the worst (least desirable or least important) criteria. Following this, the best criterion is compared against each of the other criteria, and each of the other criteria is compared against the worst criterion. A nonlinear minimax model is then employed to identify the weights, aiming to minimize the maximum absolute difference between the weight ratios and their corresponding comparisons. This method ensures an efficient and reliable weighting process by reducing the number of necessary comparisons while maintaining accuracy (Rezaei, 2016).

BWM is a pairwise comparison-based approach that offers a structured method for making comparisons, yielding several major benefits. By identifying the best and worst criteria (or alternatives) before conducting pairwise comparisons, the decision-maker gains a clear understanding of the evaluation range, leading to more reliable and consistent comparisons, as demonstrated in the original BWM study (Rezaei, 2020). The use of two pairwise comparison vectors, based on the best and worst references, mitigates potential anchoring bias through the "consider-the-opposite" strategy, which has proven effective in reducing such biases. In pairwise comparison methods, typically, either a single vector (e.g., Swing and SMART family) or a full matrix is employed(e.g., AHP). Single vector methods are data- and time-efficient but cannot check the consistency of comparisons. Full matrix methods allow for consistency checks but are less efficient and can overwhelm the decision-maker with too many questions, leading to confusion and inconsistency (Rezaei, 2020). BWM strikes a balance by being data- and time-efficient while still enabling consistency checks through its structured use of two vectors, avoiding the pitfalls of an incomplete comparison matrix. In cases with more than three criteria, BWM's original non-linear model might yield multiple optimal solutions, reflecting data inconsistency. This flexibility is beneficial in group decision-making, as multiple optimal solutions increase the likelihood of finding a compromise that aligns with one of the optimal solutions. While multiple solutions can be advantageous, especially in group contexts, a unique solution is sometimes preferred. The linear BWM model addresses this by providing a unique solution (Rezaei, 2020).

4.3.2. Bayesian Best Worst Method Steps & Mathematical Representation

The following mathematical steps are followed to conduct the Bayesian Best Worst Method:

Step 1:
The researcher has identified a set of contexts for this study: stakeholder, data, and blockchain (C). These contexts encompass a range of diverse values $(C_1, C_2, ..., C_n)$ identified through a literature review, participatory observations, and interviews.

$$C = C_1, C_2, ..., C_n \tag{4.1}$$

Step 2:
In this step, the decision-maker is asked to select the best C_B and the worst criteria C_W from the provided list determined in step 1. At this stage, no pairwise comparisons are conducted; the decision-maker simply identifies the most and least desirable values.

Step 3:
Now, the decision-maker is asked to conduct the first pairwise comparison based on the best criterion C_B selected. Using this best criterion as a benchmark, the decision-maker assigns a number from 1 to 9 to each of the other criteria. A value of 1 indicates that the criterion is equally important as the best criterion, while a value of 9 signifies that the best criterion is extremely more important than that specific criterion. This pairwise comparison results in the "Best-to-Others" A_B vector.

$$A_B = A_{B1}, A_{B2}..., A_{Bn} \tag{4.2}$$

where A_{Bj} represents the preference of the best C_B to $C_j \in$ C.

Step 4:
In this step, the decision-maker is asked to perform the same task as in step 3, but this time based on the worst criterion C_W. Using the worst criterion as a benchmark, the decision-maker assigns a number from 1 to 9 to each of the other criteria. This pairwise comparison results in the "Worst-to-Others" A_W vector.

$$A_W = A_{1W}, A_{2W}..., A_{nW} \tag{4.3}$$

where A_{jW} represents the preference $C_j \in$ C over the worst C_W.

Step 5:
The final step in the Best-Worst Method Analysis is the calculation of the optimal weights.

$$w = w_1, w_2..., w_n \tag{4.4}$$

Having obtained A_B and A_W a new weight vector which is in the proximity of $w_B/w_J = a_{Bj}$ and $w_j/w_W = a_{jW}$ for J = 1,2,..,n. So the maximum absolute difference could be minimized as $\left|\frac{w_B}{w_j} - a_{Bj}\right|$ and $\left|\frac{w_j}{w_W} - a_{jW}\right|$ for all j= 1,2,..,n. Additionally, the weight vector must satisfy the non-negativity and unit-sum properties. Consequently, the following optimization problem is used to find the optimal weight vector w:

$$\begin{aligned} &\min_{w} \max_{j} \left\{ \left| \frac{w_B}{w_j} - a_{Bj} \right|, \left| \frac{w_j}{w_W} - a_{jW} \right| \right\} \\ &\text{s.t.} \quad \sum_{j=1}^{n} w_j = 1, \quad w_j \geq 0 \quad \forall j = 1, 2, \ldots, n. \end{aligned} \tag{4.5}$$

Similarly, the weight vector can be determined by solving the following optimization problem:

$$\begin{aligned} &\min_{\xi, w} \xi \\ &\text{s.t.} \quad \left| \frac{w_B}{w_j} - a_{Bj} \right| \leq \xi \quad \forall j = 1, 2, \ldots, n \\ &\qquad \left| \frac{w_j}{w_W} - a_{jW} \right| \leq \xi \quad \forall j = 1, 2, \ldots, n \\ &\qquad \sum_{j=1}^{n} w_j = 1, \quad w_j \geq 0 \quad \forall j = 1, 2, \ldots, n \end{aligned} \tag{4.6}$$

Solving equation 4.6 leads to the determination of the optimal weights $w = w_1, w_2..., w_n$ and ξ. ξ is used to ensure the consistency of the answers of a decision-maker.

4.4. Data Collection Method

4.4.1. Method Selection

As mentioned in **section 4.3**, both surveys as well as interviews can be used to get input from decision-makers. Interviews are an excellent means of delving deeply into a certain area of interest and genuinely addressing the core of the matter. It is a dynamic method because it lets you inquire further. In addition to providing insight into the responses, interviews may also yield additional information for study through body language or tone. However, because they are typically one-on-one, interviews take a lot of time. On the other side, surveys save time and effort. It is also employed when you would prefer to receive a response rather than in-depth information. Given the constraints and requirements of this research, such as the short time period and restricted resources, an online survey is employed for data collection.

4.4.2. Survey Design

The survey for this study was developed using the Qualtrics Survey Software, which is provided under a student license from TU Delft. For the complete survey, please refer to **Appendix C**. The survey is created by taking benchmarks from master thesis examples such as Lanzini (2020) and Lopes Vieira (2022). When creating the survey, particular emphasis is placed on the three components recommended by Sekaran (2016): the wording of the questions, the planning of how the variables would be categorized, scaled, and coded, and finally the overall appearance of the survey leading to take simplicity as the main objective during the creation. All questions in the survey are close-ended, meaning respondents could only select from the provided multiple-choice options or use a slider to indicate the importance of specific values. This approach also ensured the creation of vectors for the Bayesian Best Worst Method.

The survey begins with an opening statement introducing the study and its significance. The goal of the study is outlined, along with the researcher's name and contact details. Additionally, the opening statement includes an estimated time requirement for completing the survey and an overview of the method to be used. Lastly, survey takers are informed about the potential risks of participating, and their consent is requested. Instead of requesting a signature, clicking the next button serves as validation, as no personal data is retained. Prior to participants answering questions, a phase of common understanding is established, aiming to align all survey takers with the same mindset. This phase introduces the concepts of a data-sharing consortium in the aviation industry and blockchain technology. It outlines the three main actions that survey participants undertake. This approach ensures that all respondents have a clear understanding of the context and objectives of the survey before proceeding to answer the questions. The survey initiation involves presenting three initial questions directed at the respondent. These questions serve as a filtering mechanism, eliminating participants unfamiliar with the aviation industry. Following this, respondents are prompted to provide details regarding the scope of their employing organization and their specific job designation. This comprehensive data collection enables a validation point that all the stakeholders' opinions within the industry are considered and a potential analysis based on the organizational context or individual roles within the industry, enhancing the depth and relevance of subsequent survey findings.

Following the introductory segment, the main body of the survey commences with nine blocks of questions. The initial block pertains to layer 1 context as presented in **Figure 4.1**, followed by three distinct blocks dedicated to layer 2 values, focusing individually on data, blockchain, and stakeholder values. Subsequently, five blocks are allocated to the third layer sub-values: one for data and four for stakeholders. Each block comprises identical questions tailored to various values, prompting respondents to rank them from best to worst accordingly. The questions are structured based on the guidelines provided by Rezaei (2015) and previous Master Thesis examples such as Lanzini (2020) and Lopes Vieira (2022). All definitions of values are included at the beginning of the survey questions so that respondents can refer to them at any time. An illustrative example of scoring is also provided for only the first two questions. This approach aims to streamline the survey process and eliminate confusion, as including examples in every question would necessitate continual reference checks, potentially disrupting the flow of responses.

In reviewing the survey design, it is imperative to address certain limitations, particularly concerning its length. The extensive duration of the survey presents several concerns. Firstly, it may contribute to respondent fatigue, potentially leading participants to feel overwhelmed or lose focus, resulting in rushed or incomplete responses. Additionally, the considerable duration of the survey may deter individuals from participation, as it may be perceived as excessively time-consuming. The following steps have been taken to address this issue.

4.5. Scoping of Values

The merged findings from the literature review, participatory observations and interviews are consolidated into a three-tiered value classification scheme, as shown in **Figure 4.1**. However, several adjustments need to be made to utilise the survey effectively. To maintain the survey's effectiveness and accuracy, its duration must not exceed 10 to 15 minutes (Qualtrics, 2024). Past research indicates that longer surveys tend to result in participant fatigue and boredom, leading to skewed results. Therefore, these adjustments are important to optimize participant engagement and the reliability of the survey findings.

Firstly, the value of privacy identified in the literature review is merged with access control. The rationale behind this decision is that both concepts are intrinsically related; addressing access control inherently ensures the protection of privacy. By consolidating these values, the focus is streamlined on access control, which comprehensively encompasses the necessary measures to safeguard privacy.

Secondly, the stakeholder values of Social Acceptance and Internal Support identified in the literature were deliberately excluded from the final table. This decision stems from two main considerations. Firstly, for the sake of simplicity and efficiency, Jafar Rezaei's Best Worst Method suggests that having nine or more criteria can be excessive for stakeholders and may require further categorization (Rezaei, 2020). This insight makes it clear that an elimination is necessary to streamline the decision-making process. Furthermore, during the interviews, the stakeholders did not mention social acceptance and internal support. Their absence from the discussions indicates that these values are not as pertinent to the stakeholders' immediate concerns. Therefore, to maintain focus on the most relevant and frequently cited values, these two are omitted from the final analysis. This approach ensures that the analysis remains both manageable and directly aligned with the priorities expressed by the stakeholders.

The concept of ease of use in technology is intrinsically linked to its understandability. For technology to be regarded as user-friendly, it must be easily understood (Smith, 1986). Modern design principles emphasize the importance of creating interfaces that are not only comprehensible but also intuitive, enabling users to navigate them effortlessly. This integration of usability and understandability ensures that, from the perspective of the end user, there is no significant difference between the ability to use a technology with ease and the understanding of its functionality. The final version of value layers can be seen in **Figure 4.1**.

Finally, simplified definitions are created for each value to enhance clarity and effectively communicate to survey participants. These definitions can be seen in **Appendix B section B.2**

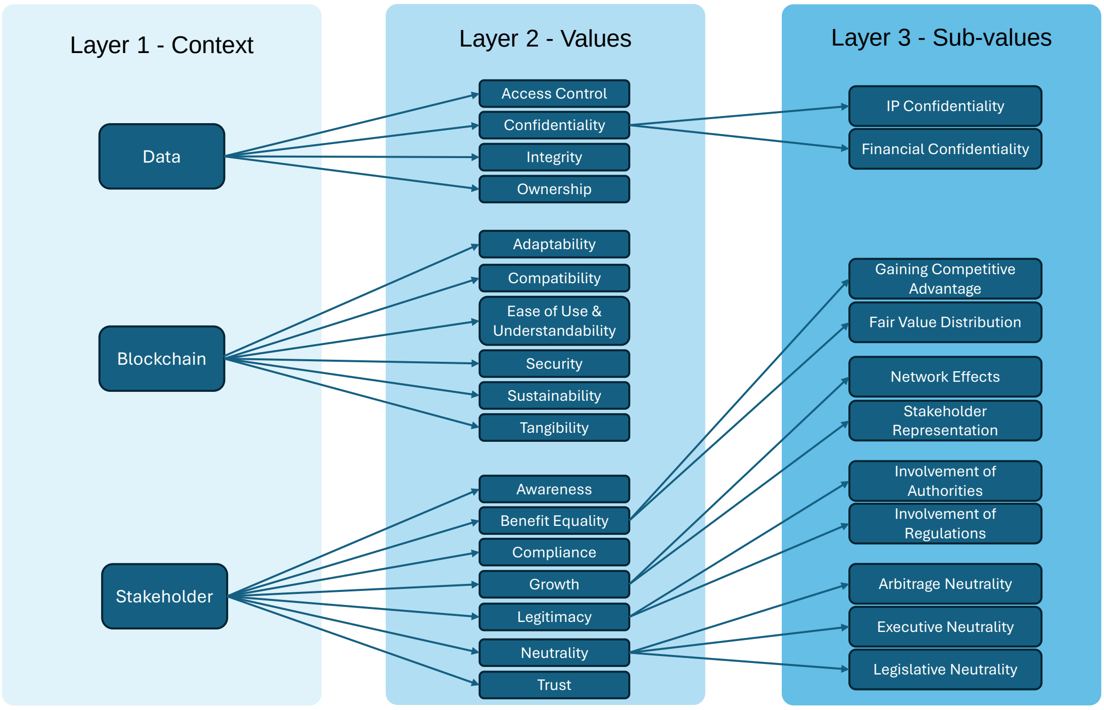


Figure 4.1: Value Layers

4.5.1. Questionaire Respondent Sampling

A total of 90 experts are contacted via email, employing a non-probability sampling method, specifically judgment sampling, due to the study's narrow focus and tight time constraints (Sekaran, 2016). These experts were carefully selected based on their experience in the aviation industry and their likelihood to join data-sharing consortiums. Although some of these experts had knowledge and experience in blockchain technology, it was not a prerequisite; the survey began with an explanation of the technology to ensure all participants had a uniform understanding. To ensure the appropriate individuals responded to the survey, the first question in the introduction block, as shown in **Appendix C**, asked about familiarity with the aviation industry. This approach helped eliminate misleading participants or answers.

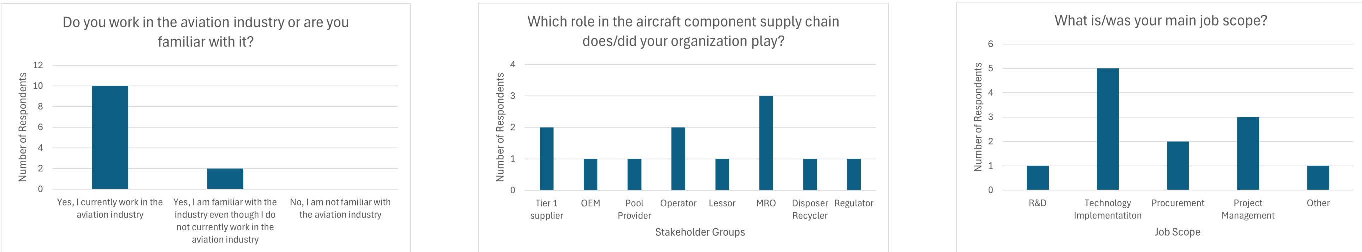
The potential respondents included participants from previous interviews as well as entirely new experts. The primary goals were to obtain feedback on the research's progress and to gather new, unbiased perspectives. The survey was distributed to a large number of recipients in anticipation of a low response rate, acknowledging that the survey's duration of around 20 minutes is double the ideal survey length (Sekaran, 2016). Ultimately, 12 responses are received, yielding a response rate of 13.3%. Despite the limited sample size, the objective of this research is not to generate generalizable findings. Instead, it seeks to shed light on the values that stakeholders prioritize while participating in an aviation blockchain consortium. This low response rate was also examined by (Rezaei et al., 2018) himself during the investigation into the selection of a sustainable product-package design. He considered the various actors within a food supply chain and noted the limited number of high-level executives within a company. This response rate serves as the foundation for the result evaluation and discussion.

4.6. Data Analysis

4.6.1. Respondent Overview

As mentioned in **subsection 4.5.1**, the survey is primarily distributed through the supervisors' personal network, with assistance from the researcher. Determining the true reach (audience size) of the survey or the number of people who start but do not complete is not traced. This approach is taken to minimize the collection of unrelated data and avoid unnecessary privacy issues. Finally, it should be noted that the survey was pre-tested with three participants who were not part of the main research. This was done to assess its understandability, identify any mistakes, and ensure its effectiveness.

The initial set of data that can be analyzed involves the number of respondents (12) who have completed the survey. Among these respondents, 10 (83%) are actively working in the aviation industry, while 2 (17%) are familiar with the industry but not currently employed in it. No respondents are unfamiliar with the aviation industry, as judgment sampling is employed. Additionally, all eight stakeholder groups as identified in **subsection 2.5.2** are represented by at least one respondent. Notably, certain stakeholder groups, such as tier 1 suppliers and operators, have 2 respondents each, and MROs are represented by 3 respondents.



(a) Respondents Knowledge in Aviation Industry

(b) Companies Role in Aviation Industry

(c) Respondents Job Scope in Aviation Industry

Figure 4.2: Initial Data of Respondents

Regarding the job scope of the respondents, 5 (42 %) are involved in technology implementation, 3 (25 %) in project management, 2 (17 %) in procurement, 1 (8 %) in R&D, and 1 (8 %) is responsible for airline global MRO issues. This diverse representation ensures a comprehensive perspective on the various aspects of the aviation industry.

These distributions which are visualized in **Figure 4.2** underscores the thorough and targeted nature of the survey, ensuring that insights are gathered from a wide range of relevant stakeholders within the aviation sector. By leveraging personal networks and targeted sampling, the research maximizes the relevance and accuracy of the data collected while maintaining a focus on privacy and minimizing unnecessary data collection.

4.7. Results

This section discusses the calculated value weights for all stakeholders as seen in **Figure 4.3**. The MATLAB code that was used for calculating the weight and credal rankings can be seen in **Appendix E**. The calculated weights demonstrate the holistic weight that individuals have attributed to the contexts and values. The individual responses per stakeholder can be found in **Appendix C section C.3**. Before conducting an in-depth analysis, it is evident from an intuitive perspective that the values with the highest final weights are preferred the most by the overall stakeholders. However, the confidence in the superiority of these values cannot be established solely by comparing their final weights and requires further discussion.

For this reason, the credal ranking system is employed within the BWM to ascertain the confidence that one value is superior to another. This ranking can also be readily converted into a traditional ranking. Mathematically, it can be stated that $P(vi > vj) + P(vj > vi) = 1$. Consequently, vi is considered more important than vj if and only if $P(vi > vj) > 0.5$. Thus, the traditional ranking of criteria can be obtained by applying a threshold of 0.5 to the credal ranking.

The final value table, as seen in **Figure 4.3** created for this study, contains three hierarchy layers, and the calculation of the final weights follows a four-step procedure. First, the global weights (GW) of the context layer are determined. Secondly, the local weights (LW) are determined for the values. Third, the sub-local weights (SLW) are calculated. Finally, the final weights (FW) are calculated by multiplying the global weights with the corresponding local weight values, and a ranking of the weights is conducted. Sub-local weights are excluded from the final weight calculation to avoid inconsistencies. This exclusion is necessary because not all values have corresponding sub-values. Including sub-local weights would result in an uneven ranking process, as the weights would be multiplied by an additional factor between 0 and 1, leading to discrepancies in the final ranking. These sub-local weights are further elaborated and used during the creation of governance arrangements in **chapter 6**; however, in this pure mathematical calculation, they are left out.

Layer 1		Layer 2				Layer 3	
Context	Global Weight	Value	Local Weight	Final Weight	Ranking	Sub-Value	Sub-local Weight
Data	0.4496	Integrity	0.2463	0.11073648	3	-	-
		Access Control	0.2646	0.11896416	1	-	-
		Confidentiality	0.2613	0.11748048	2	IP Confidentiality	0.415
						Financial Confidentiality	0.585
		Ownership	0.2278	0.10241888	4	-	-
Blockchain	0.205	Security	0.2034	0.041697	10	-	-
		Tangebility	0.1754	0.035957	12	-	-
		Ease of use & Understandability	0.1111	0.0227755	17	-	-
		Sustainability	0.1522	0.031201	14	-	-
		Compatibility	0.1706	0.034973	13	-	-
		Adaptability	0.1872	0.038376	11	-	-
Stakeholder	0.3454	Benefit Equality	0.1227	0.04238058	9	Fair Value Distribution	0.4461
						Gaining Competitive Advantage	0.5539
		Compliance	0.155	0.053537	8	-	-
		Awarness	0.077	0.0265958	15	-	-
		Legitimacy	0.1727	0.05965058	6	Involvement of Authorities	0.455
						Involvement of Regulators	0.545
		Neutrality	0.1693	0.05847622	7	Legislative Neutrality	0.393
						Executive Neutrality	0.39
						Arbitrage Neutrality	0.2169
		Trust	0.2268	0.07833672	5	-	-
		Growth	0.0764	0.02638856	16	Network Effects	0.5435
						Stakeholder Representation	0.4565

Figure 4.3: Stakeholder Values Weights

4.7.1. BWM Results: Layer 1 Context

In this section of the survey, participants were asked to rank the importance of three contexts: the data to be shared and received, the stakeholders involved in the consortium, and the blockchain platform to be utilized.

For the overall population of stakeholders, data emerges as the most crucial context, with a significance score of 0.4496. This underscores the value stakeholders place on data, as seen in the analysis of the interviews in the previous chapter, viewing it not just as an auxiliary tool but as a fundamental asset for their companies. Following data, stakeholders come in as the second most important context, with a significance score of 0.3454. This highlights the importance of the network of participants within the consortium and suggests that the third context blockchain is primarily seen as a means for data sharing rather than the main focus. Hence, companies emphasize the importance of the data itself and the stakeholders involved in its exchange over the specifics of the technology used.

Upon examining individual responses from the 12 survey participants, none indicated that blockchain was the most important factor. Instead, seven participants (58%) identified data as the most critical context, while five participants (42%) considered stakeholders to be the most important. This distribution further validates the emphasis placed on data and stakeholder relationships over the blockchain technology itself.

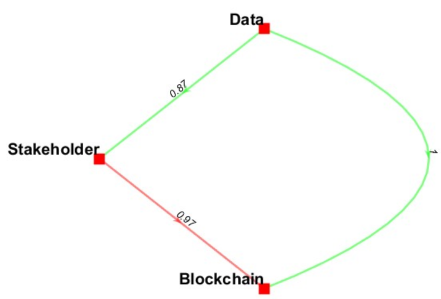


Figure 4.4: Visualization of the credal ranking for Layer 1 - Context

In addition to considering the average weights, it is valuable to examine the confidence levels regarding the superiority of one context over another. As indicated in **Figure 4.4**, the confidence relationships between the different contexts are notably high, with all three confidence values exceeding 0.85. This high level of confidence signifies a strong consensus among participants.

The data context holds a perfect confidence score of 1, unequivocally establishing its superiority over the blockchain context. The confidence level between data and stakeholders is slightly lower at 0.87, yet it remains robust. This strong confidence might reflect the importance some stakeholders place on having a robust network to support their data-driven needs. Essentially, stakeholders with a significant focus on data may also value the presence of numerous and well-coordinated partners within the consortium. This slightly lower confidence level, while still strong, suggests that while data is critical, the relationships and interactions between stakeholders also play a vital role.

4.7.2. BWM Results: Data

The survey proceeded by asking participants to rank their values within the data context, specifically focusing on integrity, access control, confidentiality, and ownership. These four values emerged not only as the top priorities within the data context but also as the most important values overall among all possible selections. This once more underscores the importance stakeholders place on data.

Within the data context, access control emerged as the most important value, with a significance score of 0.119. This indicates that stakeholders are particularly concerned about the potential for their data to be accessed by other parties, especially competitors. Ensuring robust access control mechanisms is thus seen as a critical function that must be facilitated. However, the difference in the final weights of these values is minimal, with confidentiality scoring 0.117, integrity at 0.110, and ownership at 0.102, which highlights the need for further analysis.

An examination of individual results reveals that access control is selected as the most important value by six participants (50%). Interestingly, of these six participants, three (50%) also placed equal importance on ownership. This potentially indicates a perceived relationship among stakeholders that controlling data inherently implies owning it. Integrity is the second most selected value, with five participants (42%) identifying it as their top priority. Given the close weights of these values and the limited insights gained from individual responses, it is evident that further analysis based on confidence intervals is necessary.

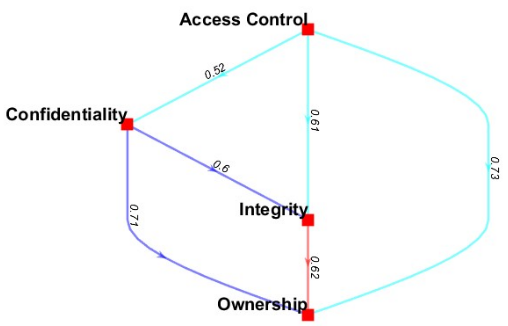


Figure 4.5: Visualization of the credal ranking for Layer 2 - Data

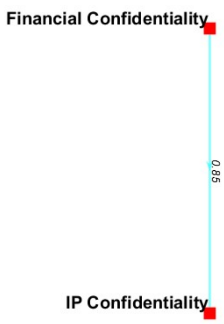


Figure 4.6: Visualization of the credal ranking for Layer 3 - Confidentiality

Regarding confidence intervals in **Figure 4.5**, it is challenging to establish a clear superiority among the values, with the highest confidence being 0.73 and the lowest, between access control and confidentiality, at 0.52. The difficulty in establishing clear superiority with these confidence intervals underscores the complex and multifaceted nature of stakeholder concerns regarding data. This ambiguity suggests two possible interpretations. First, there may be no definitive hierarchy among these values, implying that stakeholders consider all aspects of data equally important and a holistic approach to data governance is required. Such an approach would ensure that all these aspects are addressed concurrently, preventing potential vulnerabilities that might arise from focusing on a single area. Alternatively, these values may be interrelated, indicating that addressing one value could trigger a domino effect, thereby facilitating the resolution of the others more efficiently. For instance, enhancing data access control mechanisms could inherently improve data ownership perceptions among stakeholders.

Finally, an analysis of the third layer of confidentiality, distinguishing between financial and IP confidentiality, is conducted. Individual results reveal that six participants (50%) rated financial confidentiality as more important, while three respondents (25%) considered both equally important. Despite this, a confidence level of 0.85 indicates a strong preference for financial confidentiality over IP confidentiality, as seen in **Figure 4.6**. This suggests that stakeholders are particularly focused on protecting financial data, viewing it as highly sensitive and vulnerable to competitive threats.

4.7.3. BWM Results: Blockchain

In the subsequent section of the survey, participants were asked to rank their values within the blockchain context, specifically security, tangibility, ease of use and understandability, sustainability, compatibility, and adaptability. Although blockchain is perceived as the least important context, the values derived from this ranking can still significantly impact governance arrangements.

Security of the blockchain against malicious attacks emerged as the most critical value, with a weight of 0.042. This is followed by adaptability (0.038) and tangibility (0.036). This ranking indicates that stakeholders prioritize not only the immediate protection of the blockchain but also its long-term functionality and relevance. Tangibility is crucial for understanding the technology's current benefits and demonstrating its value to others. Simultaneously, stakeholders value adaptability, ensuring that the blockchain can accommodate new participants and manage the departure of existing ones, thereby maintaining the platform's long-term viability. Interestingly, sustainability, although a prominent topic in aviation, ranked 14th among the values in the context of a data-sharing consortium, with a final weight of 0.031. This lower ranking suggests that, within this specific context, immediate operational concerns outweigh broader environmental considerations. The least important value identified is ease of use and understandability, which is unexpected. While ease of use and understandability are important, they might be perceived as less critical in the immediate context of establishing and securing the blockchain platform.

Upon investigating individual results, it was found that three participants (25%) selected security as their most important value, while another three (25%) chose tangibility as their top priority. Additionally, apart from these six, two additional participants (20%) indirectly selected both of these values as their most important by initially choosing one and then placing equal importance on the other. The emphasis on security suggests that participants are highly concerned with the protection of the platform, while the importance placed on tangibility indicates a need and desire for practical implementation of the technology. This data underscores the need to focus on both security and tangibility when creating governance designs, as these aspects are crucial to the majority of participants.

Upon examining the confidence intervals in **Figure 4.7**, it is observed that out of the 15 confidence intervals, 10 exhibit a confidence level of 0.75 or higher. However, the remaining 5 intervals introduce a degree of uncertainty, reflecting the broad range of stakeholder opinions. This uncertainty could be addressed by either surveying a larger group of participants or further exploring stakeholder perspectives through detailed interviews regarding the provided answers.

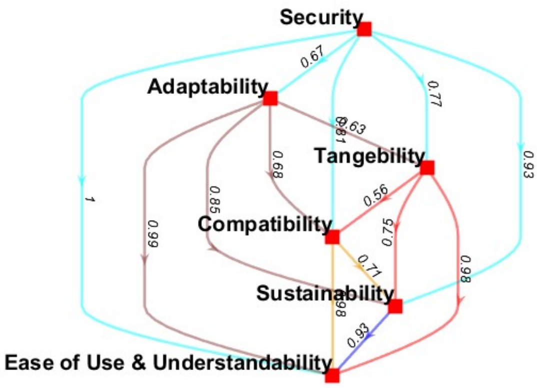


Figure 4.7: Visualization of the credal ranking for Layer 2 - Blockchain

4.7.4. BWM Results: Stakeholder

In the final phase of the interviews, stakeholders were asked to rank values within the stakeholder context. This part of the interviews proves to be the most challenging and lengthy, as it involves evaluating seven different values, with four of these values being extended to nine sub-values, as shown in **Figure 4.3**.

Among the primary seven values, trust emerges as the most important, with a final weight of 0.078. This finding underscores that, despite the objective of blockchain technology to create a trustless environment for data commitment, the process of joining and contributing to the platform fundamentally begins with trust. This superiority becomes even more pronounced upon analyzing the individual responses, which indicate that 8 (75%) of all respondents identified trust as their most important value. Trust is followed by legitimacy (0.060), neutrality (0.059), and compliance (0.054), which are very close in weight. Although these values are relatively comparable in terms of weight, a slight superiority can still be theoretically significant if all respondents score the superior value slightly higher than the others. Once **Figure 4.8** is analyzed, this becomes evident in the confidence intervals between legitimacy and compliance (0.75) and compliance and neutrality (0.71). However, the confidence interval between neutrality and legitimacy is 0.55, just above the threshold of 0.5, indicating that these two objectives are of almost equal importance. In practice, objectives with similar weight values typically have lower confidence intervals. Nonetheless, the finding that 17 of the potential confidence intervals are at or above 0.97 demonstrates a strong consensus among stakeholders about the superiority of these values. This high level of agreement indicates a unified perspective on the importance of trust, legitimacy, neutrality, and compliance within the stakeholder context.

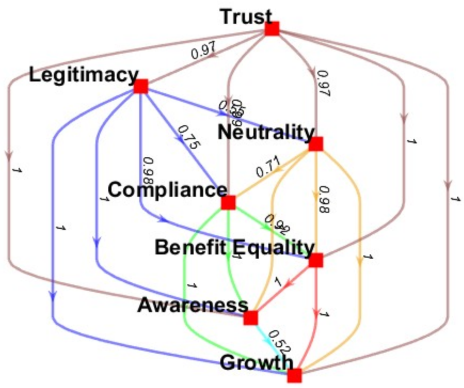


Figure 4.8: Visualization of the credal ranking for Layer 2 - Stakeholder

Once the third layer of these values is analyzed, the most striking observation is the weight differences within the neutrality value. While the weight differences for all other values are around 0.1, the values of neutrality show a difference of nearly 0.2 between arbitrage neutrality and legislative and executive neutrality. This suggests that although stakeholders desire the involvement of a neutral central authority, they prefer this neutrality in the execution and legislative functions (namely, in the creation and implementation of rules) rather than in the arbitration or punishment of rule violations. This disparity indicates a need for further investigation, but it could indicate that stakeholders expect this neutrality to be maintained through automated smart contracts rather than through a subjective judgment entity. Additionally, when the confidentiality between legislative and executive neutrality is investigated, no clear superiority (0.51) can be established. This indicates that stakeholders consider the implementation of both legislative and executive neutrality to be equally important, as seen in **Figure 4.9**.

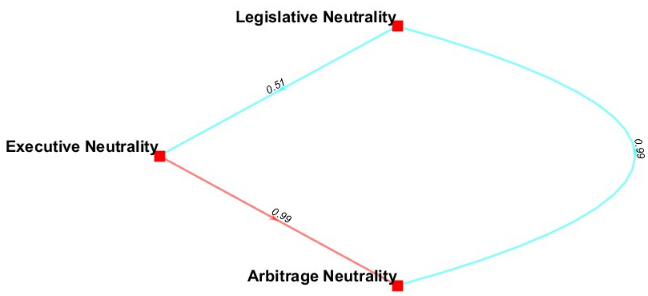


Figure 4.9: Visualization of the credal ranking for Layer 3 - Neutrality

For the remaining values in layer three, the superiority of gaining competitive advantage (0.77), network effects (0.71), and involvement or adherence to existing regulations (0.72) is established. The figures of these intervals can be seen in **Appendix C section C.4** However, it is important to note that upon examining individual results, it is found that 5 stakeholders marked both benefit equality values, 4 stakeholders marked both growth values, and 6 stakeholders marked both legitimacy values as equally important.

This could be due to the possibility that these values are inherently interconnected in the eyes of stakeholders and difficult to distinguish from one another. For instance, involving authorities in the consortium might naturally entail adherence to their pre-existing regulations. Similarly, as the network grows, a diversity of stakeholders is likely to emerge automatically, influencing the overall dynamics and benefits distribution within the consortium. Further investigation needs to be carried out regarding these values.

4.8. Conclusion

This chapter addressed the second sub-research question:

Sub-Research Question 2: What are the critical values of stakeholders for designing governance arrangements?

The analysis of the survey outputs and subsequent BWM results are presented. Each subsection discusses the local weights, individual results, and the credal ranking regarding values. Examining the global weight, it becomes apparent that participants of a blockchain platform prioritize the data that will be shared and received. This is followed by the importance placed on the stakeholders who will participate on the platform, and the blockchain platform itself is deemed the least important. Furthermore, due to the high importance stakeholders place on data, the values within the data context emerge as the most significant overall. These values are prioritized in the following order: access control, confidentiality, integrity, and ownership, which can also be seen from the ranking column of **Figure 4.3**. This finding highlights that any data-sharing initiative must first address all aspects of data before progressing to other considerations.

Data values are followed by the four most important values within the stakeholder context: trust, legitimacy, neutrality, and compliance. This finding underscores that such initiatives are primarily initiated by organizations that already have mutual trust. These efforts are further facilitated by regulators and approved protocols, given the highly regulated nature of the industry. However, as the platform becomes more distributed, encompassing multiple entities, it is crucial to maintain neutrality in governance and adhere strictly to established rules.

There is a notable decrease in the final weight starting from the value of compliance, indicating a clear cut-off point. Still, as the benefits of this platform continue to grow, it is essential to ensure that these advantages are equitably distributed among all participants. This equitable distribution fosters a fair and collaborative environment, which is vital for the long-term success and sustainability of the initiative. Awareness and growth, the final two values within the stakeholder context, are not assigned as much importance. However, this does not imply that they are insignificant. Specifically, growth is anticipated to become crucial in the longer stage. Still, because most of the entities are situated at the initial stage of the platform, this is not a priority. While awareness should be vital at this stage, it is unclear why stakeholders did not prioritize it. This lack of emphasis on awareness might be perceived as a significant barrier to overcome.

Finally, within the context of blockchain values, system security is considered the most crucial aspect, highlighting the need to protect the platform from potential cyberattacks. Following security, adaptability emerges as the second most important value. This is encouraging, as it indicates that stakeholders prioritize long-term considerations from the outset. Next is tangibility, which ranks lower than anticipated, particularly given its significant importance observed during the participatory observations conducted for this research. This lower ranking could be mainly due to the low global value attributed to blockchain, yet it remains a critical value that needs immediate attention. Compatibility comes next, ensuring that the blockchain system integrates seamlessly with existing technologies and processes, thereby facilitating smoother transitions. Sustainability is ranked 14th, which is unexpected considering the significant emphasis on environmental friendliness throughout all aspects of the aviation industry. Finally, ease of use and understandability is considered the least important value.

The ranking of values now identified provides a clear roadmap for the governance design process. This ensures that the final governance design is comprehensive and pragmatic by focusing on the values with a higher final weight first, enabling effective and sustainable blockchain implementation for part tracking in the aviation industry. The next chapter examines how researchers and industry players have designed governance mechanisms up to this point for a benchmarking study, exploring also whether these values are already inherently included. Later in **chapter 6**, design suggestions for the top eight most important values are made.

5 Governance Mechanisms in Blockchain Consortium

5.1. Introduction

The following chapter addresses the third sub-research question:

Sub-Research Question 3: How are governance mechanisms currently designed within blockchain consortiums?

This question is answered through desk research, drawing on both literature papers and real-world project documentation. This chapter aims to analyze how governance mechanisms are currently designed and agreed upon within existing blockchain consortia. These governance mechanisms will be essential for selecting designs that align with the most important values identified through the BWM. The objective is to utilize this analysis as a benchmarking and brainstorming tool. To accomplish this, it is essential to explore several foundational topics first. In **section 5.2** background research question 3A is answered as stated in **section 1.3** by discussing the need for governance among stakeholders. Once the necessity is established, the discussion moves on to what blockchain governance entails in **section 5.3** answering background research question 3B. While investigating this definition a research gap regarding consortium blockchains is identified and discussed in **section 5.4**. In **section 5.5** the research continues by investigating various governance mechanisms across different layers which are further explored by the distinction between dynamic and static governance mechanisms in **section 5.6** answering background research question 3C. Finally, the theoretical part of the research transitions to practical applications with an examination of governance mechanisms and how they are agreed upon in real-world projects in **section 5.7**. This section highlights how theoretical concepts are put into action, offering valuable insights into the effectiveness and challenges of different governance approaches. The chapter concludes in **section 5.8** with a comprehensive definition of blockchain governance, a list of governance mechanisms and their respective governance design to provide a holistic view of blockchain governance.

5.2. Need for Blockchain Governance

The significance of blockchain governance becomes evident when considering real-world examples, such as the findings of Ávila et al. (2022), who examined a case study on blockchain-base traceability service for the animal protein supply chain. Ávila et al. (2022, p.1) states that a primary reason for the inability to extend pilot programs to subsequent stages is "[...], the lack of a proper governance model to govern the relations between actors and to meet corporate compliance standards hampered that (the expansion of the ecosystem around the solution) effort." The World Bank further substantiates the correlation between governance and stakeholder participation, which is crucial for technologies like blockchain, where success is highly dependent on network effects. Niforos (2018, p.1) states, "Developing a proper governance and regulatory framework for blockchain-based applications will be essential to enhance market participation while providing the stability they need to fully engage with the technology". Once the relationship between governance enabling industry engagement and industry engagement contributing to an increase in potential success is understood, defining blockchain governance within this research becomes critical.

The research does not rely on a single search engine; instead, papers are sourced from multiple platforms, including Scopus, Science Direct, IEEE Explore, and Google Scholar. This approach is necessary because single search engines provide a limited number of published papers, necessitating the use of multiple platforms to obtain a comprehensive collection of relevant literature. The primary search terms utilized are Blockchain, Consortium and Governance.

The total number includes duplicate publications. For that reason, it is important to say that finally, the analysis of

Table 5.1: Blockchain Consortium Governance Search Results

Search Term	Search Engine	Refined By	Results (N)	Relevant (N)
Blockchain AND Consortium AND Governance	Scopus	Language: English Relevant Field: Business Management Years: 2020 - 2024	11	5
Blockchain AND Consortium AND Governance	IEEE Explore	Language: English Publication Topic: Consortium Blockchain Criteria: Relevant Title and Abstract	21	3
Blockchain AND Consortium AND Governance	Google Scholar	Language: English Additional Key Words: Business Management Criteria: Citation above 20, Relevant Title and Abstract	25	8
Blockchain AND Consortium AND Governance	Science Direct	Language: English Subject Areas: Business Management Criteria: Research Articles, Relevant Title and Abstract	134	12

blockchain governance encompasses 19 distinct papers, each examining various elements. An overview of the papers can be seen in Appendix D **Table D.2** and **Table D.3**. The papers are investigated based on the types of blockchain investigated, the specific definitions of governance provided, the particular governance mechanisms explored, and the governance layers addressed.

5.3. Blockchain Governance Definition

The definitions of blockchain governance exhibit considerable variation across the papers. Of the 19 papers reviewed, 11 (58 %) provided explicit definitions, while 8 (42 %) refrained from offering a specific definition but, instead, delineated it through governance mechanisms. Among the 11 papers that did provide definitions, nine distinct definitions are identified, with two definitions appearing twice: ”The means of achieving the direction, control, and coordination of stakeholders within the context of a given blockchain project to which they jointly contribute.” by Leewis et al. (2021) and Pelt et al. (2020) and ”Blockchain governance encompasses technical and social means to make decisions [...] related to [...] business, technological, legal, and regulatory aspects of a blockchain system during its whole lifecycle” by Bons et al. (2023) and Laatikainen et al. (2021). This analysis only clearly demonstrates the variation and differing interpretations of blockchain governance. Although there is a high variance in the specific definitions of blockchain governance, six (66 %) of these definitions revolve around decision rights and the determination of who makes the rules. These definitions typically focus on allocating authority and the processes by which decisions are made within the blockchain platform.

Finally, two papers specifically focus on investigating the definition of blockchain governance, namely, Ávila et al. (2022) and Leewis et al. (2021). However, while the definitions of Ávila et al. (2022) primarily relied on web sources and lacked substantiation through analytical research, Leewis et al. (2021) carried out 23 semi-structured interviews with industry experts to gather their perspectives on Blockchain governance. The ultimate finding is: ”The definition of blockchain governance and what it entails is still a question mark”.

5.4. Consortium Blockchains

Nineteen papers are carefully selected and examined first in relation to their categorization of blockchain types: public, private, and consortium. Notably, the separation between permissioned and permissionless only while analysing these papers is left out for two reasons. The initial reason is that this separation is perceived as a foundational design decision when implementing distributed ledger technology. On the other hand, it is also observed that this decision is reflected in the governance mechanisms of the studied papers, explained as follows: (Pelt et al., 2020) and (Ziolkowski et al., 2019) defines this in membership, (Leewis et al., 2021) as participation rights, (De Filippi & Loveluck, 2016) as definition of community borders. A more detailed explanation regarding blockchain governance mechanisms will be given in **section 5.5**.

Upon further reviewing the tables shown in Appendix D **Table D.2** and **Table D.3**, it is evident that only five (26 %) papers Bons et al. (2023), Greiner et al. (2024), Laatikainen et al. (2021), Tasca and Tessone (2018), and van Haaren-van Duijn et al. (2022), to date, have delved into the governance of consortium blockchains, and notably, Bons et al. (2023) and Laatikainen et al. (2021) have used the exact definition to describe blockchain governance. Most papers tend to investigate public permissionless blockchains or public permissioned blockchains, with fewer studies dedicated to private or consortium blockchains. Pelt et al. (2020) notes that ”public permissionless blockchains are often the focus due to their open and decentralized nature, which presents unique governance challenges and opportunities.” This focus, while important, leaves consortium blockchains underexplored. This gap in research suggests a need for further exploration of how consortium blockchains operate.

Simultaneously, it is crucial to justify the choice of examining consortium blockchains instead of public or private ones. Taking into account the stringent regulations imposed by the aviation industry and potential adherence to the General Data Protection Regulation (GDPR), the deployment of an open public blockchain becomes impractical due to its inherently high transparency levels. Moreover, the data to be shared is highly sensitive, presenting a visible contradiction to the low privacy assurances offered by an open public blockchain. Additionally, the limited scalability of public blockchains poses a significant concern, particularly if the objective is to realize a consortium blockchain where all stakeholders actively participate in creating the complete value chain (van Engelenburg et al., 2020). Furthermore, the monitoring and validation of stakeholder entry and exit necessitate a level of tracking and verification that is unattainable within the framework of an open public blockchain. On the other hand, private blockchains are managed by a single administrator who defines all aspects of the blockchain. This approach contradicts the goal of integrating all entities within the aviation industry, including competitors. A single administrator can lead to the centralization of power, undermining the collaborative and decentralized nature that is essential for broad industry participation and trust. For these reasons, a consortium blockchain, in which operational rights are accessible to participants and utilized within a consortium of multiple organizations, maintaining a collaborative relationship, is the most appropriate approach. This structure ensures a balanced distribution of power and fosters cooperation among all entities(van Engelenburg et al., 2020).

With the need for governance established, the justification for consortium blockchains clarified, and the differences in blockchain governance definitions acknowledged, the research proceeds to examine governance mechanisms. This exploration aims to identify the current shortcomings and effective strategies for the long-term viability of consortium blockchains. A final definition of blockchain governance is provided and further elaborated upon **section 5.8**.

5.5. Blockchain Governance Mechanisms & Layers

Governance mechanisms in blockchain refer to the set of rules, processes, and structures that dictate multiple variables within a blockchain platform (Hein et al., 2016). The primary goal of these governance mechanisms is to ensure that the blockchain operates smoothly, transparently, and fairly, aligning the values of all stakeholders and enabling the network to adapt to changes and challenges over time. Effective governance mechanisms are crucial for long-term viability and facilitating the sustainable development and evolution of blockchain platforms (van Engelenburg et al., 2020).

The review of 19 papers identified 19 distinct governance mechanisms summarized in **Table 5.2**. Among these, decision-making, decision rights, decision processes, voting, collective decisions, and demand management all share the same definition: determining who has the authority to perform specific actions and through which processes on a blockchain platform (Liu et al., 2022; Schädler et al., 2023). These terms are the most frequently mentioned, appearing in 12 out of the 19 papers (63%). This indicates that the ability to make and implement decisions is viewed as a fundamental aspect of blockchain governance. The overview of authors who have discussed this mechanism is provided in **Table 5.2**. The frequency of a mentioned mechanism is determined by counting the sources listed within the table and dividing it by the total number of papers investigated.

Following this, incentives are mentioned in 9 papers (47%), while membership/participation rights, stakeholders, platform accessibility, community borders, actors, and stakeholders are mentioned 7 times (37%). Both of these mechanisms relate to stakeholders: one addresses how to incentivize or motivate them, while the other concerns the process of inclusion and determining who should be included. Accountability, in relation to responsibility, is the fourth most mentioned governance mechanism, appearing 7 times (37%) within the investigated papers. These two concepts are often linked, as accountability is dependent upon responsibility. This highlights the emphasis on holding parties accountable for their actions within the blockchain platform.

The fifth most discussed governance mechanism involves dispute and conflict resolution, which can result in the imposition of sanctions. This mechanism is examined in 5 papers (26%), underscoring the critical need for methods that are swift, cost-effective, and accessible to resolve disputes among stakeholders. Effective dispute resolution is essential in maintaining the integrity and functionality of the blockchain platform, as it ensures that all parties can operate within a fair and just environment.

Other mechanisms such as legal compliance, funding, decentralization level, control, system architecture, and launch style of the project are each mentioned three (15 %) times. The remaining governance mechanisms are either unique or mentioned a maximum of two times, indicating a wide range of considerations and approaches in the field. These include aspects such as communication, risk management, transactional reversing, change management, external relationships, effectiveness and ethical responsibilities, each contributing to the comprehensive governance mechanisms necessary for effective blockchain management.

These mechanisms are not only discussed stand-alone but also from multiple levels, highlighting the complexity and multifaceted nature of blockchain governance. For instance, Carter (2018) differentiates governance into on-chain and off-chain categories. On-chain governance involves decision-making processes that are directly encoded into the blockchain protocol, allowing for automated and decentralized management. Off-chain governance, on the other hand, encompasses mechanisms and processes that occur outside the blockchain, often involving human intervention and traditional decision-making frameworks.

De Filippi and Loveluck (2016) embraces a similar perspective but names them as the infrastructure-level and community-level. Infrastructure-level governance refers to the rules embedded within the protocol, which ensure that the network is self-governing and self-sustaining. On the other hand, Community-level governance focuses on the small group of developers who manage the code and make critical decisions regarding the platform's design. This level underscores the human element in governance, where developers play a pivotal role in shaping the direction and evolution of the blockchain.

Table 5.2: Governance Mechanism Summary and Description

Governance Mechanism	Description	Mentioned
Decision Making, Decision Rights Decision Process, Voting, Collective Decisions, Demand Mangement	This mechanism ensures answering the question of who has the authority to do what, as well as the way how stakeholders of a blockchain platform can reach decisions that will shape the future of the platform. (Schädler et al., 2023)	Ávila et al. (2022), Hein et al. (2016), Greiner et al. (2024), Pelt et al. (2020), Liu et al. (2022), Ziolkowski et al. (2019), Beck et al. (2018), Leewis et al. (2021), van Haaren-van Duijn et al. (2022), Zachariadis et al. (2019) Akgiray (2018), Hsieh et al. (2017)
Incentive	Motivational factors (monetary or non-monetary) involved for stakeholders in the platform. Pelt et al. (2020)	Ávila et al. (2022), Laatikainen et al. (2021), Pelt et al. (2020), Liu et al. (2022) Beck et al. (2018), De Filippi and Loveluck (2016), Leewis et al. (2021), van Haaren-van Duijn et al. (2022) Zachariadis et al. (2019),
Membership, Participation Rights, Community Borders, Actors, Platform Accessibility Embedded Institutions, Stakeholders	Focuses on the way participation and membership are managed. It starts with whether a blockchain is open for anyone to join and participate. Pelt et al. (2020)	Greiner et al. (2024), Laatikainen et al. (2021), Pelt et al. (2020), Liu et al. (2022), Ziolkowski et al. (2019), De Filippi and Loveluck (2016), Leewis et al. (2021)
Accountability, Responsability	Accountability mechanisms refer to the systems and processes put in place to ensure that individuals or organizations are held responsible for their actions, decisions, and performance. Pelt et al. (2020)	van Haaren-van Duijn et al. (2022), Beck et al. (2018), Liu et al. (2022), Ávila et al. (2022), Greiner et al. (2024), Laatikainen et al. (2021), Pelt et al. (2020)
Legal Compliance, Crime	Decisions related to laws, regulations and industry policies, standards and agreements Akgiray (2018)	Laatikainen et al. (2021), Liu et al. (2022), Akgiray (2018)
Decentralization Level, Platform Ownership Status	This mechanism ensures whether a platform itself is proprietary to a single firm or is shared by multiple owners. Hein et al. (2016)	Liu et al. (2022), Beck et al. (2018), Hein et al. (2016)
Control, Monitoring	This mechanism ensures that there is adequate oversight of resources to prevent rule violation Greiner et al. (2024)	Hsieh et al. (2017), Hein et al. (2016), Zachariadis et al. (2019)
Dispute Resolution, Conflict Resolution, Sanctions	Mechanisms that are swift, cost-effective, and accessible, providing localized areas to resolve disputes between involved stakeholders, such as mediation. In case it is not resolved sanctions refers to penalties for violations Greiner et al. (2024)	De Filippi and Loveluck (2016), van Haaren-van Duijn et al. (2022), Greiner et al. (2024), Ziolkowski et al. (2019), Akgiray (2018)
Risk Management, Perceived Risk	Identifying, assessing and controlling financial, legal, strategic and security risks of the platform. Hein et al. (2016)	Hein et al. (2016)
System Architecture, Architectural Components, Consensus Mechanism, Open Source	Mechanism that incorporates requirements and functionalities of the blockchain platform. Ziolkowski et al. (2019)	Carter (2017),Ziolkowski et al. (2019), Gasser et al. (2015)
Funding, Pricing, Number of Coins Generated	The mechanism that ensures financial resources to finance the joint blockchain platform Hsieh et al. (2017)	Hein et al. (2016) , Carter (2017), Hsieh et al. (2017)
Ethical Responsabilities Congurence	By the mechanisms of congruence, Elinor Ostrom posits that the rules that govern the appropriation and provision of a resource should follow local conditions and cultural norms. Greiner et al. (2024)	Greiner et al. (2024), Liu et al. (2022)
Effectiveness, Outcomes	Mechanism that ensures solutions are effectively developed, and their executions need to meet and demonstrate performance requirements Yue et al. (2021)	Ávila et al. (2022), Gasser et al. (2015)
External Relationships, External Stakeholders	Mechanisms that ensure the relation of the platform with the media government and the external stakeholders Hsieh et al. (2017)	Hein et al. (2016), Hsieh et al. (2017)
Launch Style of Project, Formation and Context, Purpouse and Motivation	This dimension captures the relevant background information of a blockchain. Pelt et al. (2020)	Carter (2017), Pelt et al. (2020), Gasser et al. (2015)
Change Management	This mechanism ensures that the platform remains viable and feasible as the number of participants grows and the landscape evolves. Leewis et al. (2021)	Greiner et al. (2024), Leewis et al. (2021)
Roles, Status of Contributors	The different roles present such as foundation, data contributors, developers, miners Pelt et al. (2020)	Carter (2017), Laatikainen et al. (2021), Pelt et al. (2020), De Filippi and Loveluck (2016)
Communication	The formal and informal ways of communication between the stakeholders of a blockchain. It includes the available communication tools as well as meetings and working groups. Pelt et al. (2020)	Pelt et al. (2020)
Transactional Reversal	Decision on reversing unintended transactions. Ziolkowski et al. (2019)	Ziolkowski et al. (2019)

Hsieh et al. (2017) provide a different classification, identifying three distinct levels of governance: Blockchain level, protocol level and organizational level. Owner control occurs at the blockchain level, where those who own tokens or have a stake in the blockchain have a say in its governance. Formal voting happens at the protocol level, involving structured processes where participants vote on changes or proposals. Finally, centralized funding is at the organizational level, where decisions about resource allocation and project funding are made centrally, often by a core team or a governing body.

Laatikainen et al. (2021) adopts a dynamic and holistic approach, recognizing multiple governance levels that span from individual to international contexts. He identifies group, community, individual, organizational, inter-organizational, national, and international levels of governance. This approach reflects the broad scope of governance, acknowledging that decisions and processes can impact and be influenced by a wide range of actors and entities at various scales.

Together, these perspectives illustrate the diverse and layered nature of blockchain governance, demonstrating how it can be structured and managed across different levels and by various stakeholders. Each approach provides unique insights into the mechanisms and processes that underpin effective governance in blockchain systems, highlighting the importance of considering multiple dimensions and perspectives in developing and implementing governance frameworks.

For the remainder of this thesis, given its value-centric approach, governance mechanisms will not be examined at different levels. Instead of separating governance mechanisms into various categories, the researcher will allow the identified values to drive the design process. Consequently, there will be no segmentation of the value layers. Rather, **Table 5.2** will serve as a comprehensive toolbox. Decision-makers can use this toolbox to select appropriate mechanisms and design them addressing the identified values, ensuring that the governance design is aligned with the values determined by the stakeholders. This approach facilitates a more integrated and value-driven governance framework.

5.6. Dynamic Vs. Static Consortium Formation

Among the differing viewpoints about what blockchain governance actually means, entails, or at what level it should be applied, there is one final differing viewpoint among researchers: whether governance is a static process determined upfront or a dynamic one that evolves over time. Although this dynamic view has not been widely studied yet, two researchers (Laatikainen et al., 2021; van Haaren-van Duijn et al., 2022) have taken this approach.

The static view of blockchain governance entails a predetermined and fixed structure, which the founders determine during the creation phase. During this phase, decisions regarding the establishment of consensus mechanisms and roles and responsibilities are decided and will be kept throughout the whole lifecycle of the consortium, emphasizing stability and predictability. In contrast, the dynamic view puts forward an evolving nature of blockchain platforms, incorporating mechanisms that allow for adaptation and change over time, considering different lifecycle stages such as formation, operation, and crisis management.

According to (Laatikainen et al., 2021), the dynamic governance model encompasses three main stages: formation/design, operation, and evolve/crisis. The paper argues that during the formation/design phase, governance is typically more centralized, with key decisions made by a central authority to establish the foundational rules of data sharing and protocols. As the system transitions into the operation phase, governance structures evolve towards more decentralized and automated mechanisms (ensured by the system itself), integrating both technical and social governance means. Finally, during the evolve/crisis stage, it addresses how the system manages conflicts and crises, potentially leading to hard forks or re-centralization of certain governance aspects to resolve issues and ensure operational continuity.

In the second dynamic view, by (van Haaren-van Duijn et al., 2022), three stages are described as developing the initial idea and creating a consortium, translating the proof of concept into the technical infrastructure, and opening the blockchain to external partners. The first phase involves conceptualizing the blockchain project, forming a consortium of initial stakeholders, and establishing the governance framework and collaborative agreements. The second stage requires robust governance mechanisms to oversee the development and implementation of the technical aspects of the blockchain, ensuring that the infrastructure aligns with the agreed-upon governance principles, which also puts forward the need for supervision. The third stage, opening the blockchain to external partners, involves expanding the ecosystem and incorporating external stakeholders, which necessitates adaptive governance structures to manage the increased complexity and ensure that new participants adhere to the established governance framework.

Both papers highlight the importance of having governance mechanisms that are adaptable and flexible to manage the evolving parameters and challenges of blockchain platforms. These dynamic perspectives indicate that for blockchain governance to be effective, it must continually adapt to internal developments and external influences, thereby ensuring the long-term sustainability and success of the blockchain platform.

5.7. Designs of Governance Mechanisms in Real World Projects

In the previous sections, blockchain governance and its mechanisms were examined. However, it is equally important to investigate how these mechanisms are designed and implemented in real-world projects that have undergone piloting or progressed further. This practical exploration enhances the credibility and reliability of the research findings by delving deeper than theoretical research. It also allows for identifying practical challenges and nuances that may not be apparent in purely theoretical analyses, leading to more precise definitions, applications, and analyses of governance models. Additionally, examining practical business applications is essential due to the concept of Business Acumen, which suggests that if major industry players or competitors are adopting certain strategies or paths, it is likely a prudent approach to consider. The selected cases are based on their progress, specifically achieving a Technology Readiness Level (TRL) of 7 or higher. This indicates that the piloting phase has been completed, and the system has been proven to be operationally qualified (Mankins, 1995). This high level of readiness demonstrates that the governance mechanisms designs in these cases are not only theoretically sound but have also been practically validated, making the findings more robust and applicable to real-world scenarios.

5.7.1. IBM Food Trust

In August 2017, IBM initiated its 'Food Trust' project to address the significant issue of foodborne illness, which affects 1 in 10 people and poses a costly public health problem. The project was launched with 10 founding members who are interested in supply chain traceability and food authentication with blockchain technology's potential in this domain. Since its inception, additional members, such as Carrefour, have joined, expanding the network into the European market. Currently, the blockchain is hosted on the IBM Cloud, providing a secure and scalable infrastructure for the Food Trust network (IBM Newsroom, 2018).

IBM, in their Food Trust ebook, touches upon the following governance arrangements. Direct quotes are taken from the e-book to avoid any misinterpretation (IBM, 2024a).

- **Accessibility Rights:** "All users have access to enter and control their own data." "Permission to view data is granted by the entity that owns the data, with ownership defined by the act of uploading." "Users can only see the data they are authorized to view." "IBM does not own any data uploaded by users onto the network and cannot use or share this data for commercial or other purposes." These accessibility rights are defined through smart contracts defined by attribute-based access control.
- **Conflict Resolution:** "The trust model of the solution describes the set of guarantees that reinforces the security, privacy, and integrity in a network of widely diverse participants. Our model promotes collective responsibility while guarding against collusion, maintaining the integrity of the network."
- **Decision Rights:** "The Advisory Council, comprised of a range of industry representatives, helps set the rules of engagement and leads accountability in adhering to the governance agreement for the blockchain community."
- **System Architecture:** "Data connector application programming interfaces (APIs) allow enterprise IT teams to efficiently upload supply chain data from existing data stores to their IBM Food Trust network for seamless integration of data from enterprise systems to an IBM Food Trust solution network. Smaller organizations can onboard data through an easy-to-use web experience."

5.7.2. Port of Antwerp

The project began in 2017 with a pilot in collaboration with the blockchain startup T-Mining(The Maritime Executive, 2017). The aim is to tackle inefficiencies in document flow caused by physical documentation and communication issues among stakeholders. Various pilots are implemented, focusing on automating and digitizing certificates of origin and phytosanitary certificates for fruits and vegetables, as well as securing container handling. The blockchain platform developed by T-Mining ensures that only authorized personnel can collect containers, thereby preventing fraud and enhancing security(Port Technology, 2018). The governance arrangements are categorized as follows:

- **Data Authenticity:** Smart Contracts are used.
- **Decision Rights:** A consensus among consortium members needs to be established. State sets standards.
- **Membership:** Port authority involves all companies.
- **Ownership Dispute:** Appeal to courts.
- **System Architecture Development:** Companys among members decide all together how to go further and the consortium prioritizes these.
- **Transactional Reversal:** Individual responsability.

5.7.3. PharmaLedger

Initiated in January 2020, PharmaLedger utilizes blockchain technology in the healthcare sector to track the supply chain of medicine, clinical trials, and health data. The goal of this implementation is to enhance the security of patient health data, ensure secure data sharing, and combat counterfeit medicine, which poses significant risks to human health. The project is governed by a consortium comprised of 12 global pharmaceutical companies and 17 public and private entities, including technical, legal, regulatory, academic, research organizations, and patient representative organizations (European Patients' Forum, 2024). The governance mechanisms can be discussed as follows (PharmaLedger, 2024):

- **Decision Rights:** Governed by a non-profit consortium. The research is organized into various work packages that operate in close coordination. Each work package and use case is governed by one public and one private partner. Additionally, major decisions are made by majority vote in the general assembly, where all partners are represented and have an equal say.
- **Funding:** Membership Fee
- **Membership:** Different fees for different level of membership (Patron, Standard, Public Partner)
- **System Architecture:** Data and applications are stored outside of the blockchain but anchored to it. Data is anchored to the blockchain, and each layer of the blockchain relies on the layer below it. This ensures a clear and secure chain of data integrity and validation, making it easier to manage and verify the data.

5.7.4. VeChainThor

Started in Singapour in 2017, VCT's goal is to provide traceability of goods in the supply chain by linking other high-end technologies to the chain, such as smart chips, QR codes, or Radio Frequency Identification (RFID) tags. The goal of the platform later changed to helping global enterprises and governments achieve Sustainable Development Goals (SDGs) efficiently, quickly, and at low cost. Governance arrangements also studied by van Haaren-van Duijn et al. (2022) can be summarized as follows:

- **Access Control:** Applications are accessible to all members. Data Validators operate on different levels and can each access limited data.
- **Accountability:** Validators are responsible for issues that arise within the protocol and network layers, even though there is no formal contract governing their responsibilities. On the other hand, the utility provider is responsible for any problems that occur at the application layer.
- **Conflict Resolution:** An elected steering board manages all activities.
- **Decision Rights:** The foundation board has full decision power, but participants can submit proposals to the board for voting and approval.
- **Incentives:** Dual token system. Vechain token (VET) and veThor (VTHO) are used. VET acts as a utility token for transferring value, while VTHO covers the costs of using the VechainThor blockchain, representing the necessary energy. This two-token approach effectively separates the operational costs of the blockchain from market speculation, which is crucial for enterprise applications.

5.7.5. TradeLens

An effort initiated in 2018 with the assistance of IBM and Maersk, the primary objective is to improve the shipping industry's present paper-based data sharing inefficiencies while also increasing transparency and security. The initiative aimed to build trust between shipping institutions such as freight forwarders, customs, and ports. During this initiative, the following governance mechanisms are taken into account (Jovanovic et al., 2022).

- **Access Control:** Role Based Access Control
- **Confidentiality:** Opted for a permissioned blockchain with data sharing specifications referred as "consignment hierarchy".
- **Decision Rights:** A neutral advisory board is set up to indicate neutrality and openness in governing the platform. A customer advisory board is set up as the middle entity between carriers, platform developers and decision-makers to listen to the wants and needs of customers.
- **Incentive:** Create an open application marketplace for complementors to develop their own applications on the blockchain platform. Add value to the system and create a self-enforcing cycle.
- **Interoperability:** Integrating data silos with TradeLens through APIs for organizations that handle large volumes of data. Employ a user interface instead of integrating existing systems with the platform ecosystem for smaller firms.
- **Standardization:** Involve non-profit entity establish standards for the entire shipping industry.
- **System Architecture:** Load data off-chain keep hash pointers. Involve trust anchors who have an exact copy of the ledger. They participate in the consensus mechanism, meaning that they validate transactions and host data, and play a critical role in securing the network.

5.8. Conclusion

This chapter answers the third sub-research question.

Sub-Research Question 3: How are governance mechanisms currently designed within blockchain consortiums?

In conclusion, one of the ongoing barriers to achieving a long-term sustainable blockchain consortium is the lack of governance among stakeholders. This issue is further complicated by lacking a universally accepted and clear definition of blockchain governance and its mechanisms. The diversity in governance approaches indicates the need for a more standardized framework to facilitate better communication and implementation, which leads to the following conclusions.

Based on the literature overview, blockchain governance is a broad term that encompasses multiple mechanisms, making it crucial to keep its definition straightforward and further elaborate on it with the mechanism. The ultimate definition formulated for this research is: **Consortium blockchain governance refers to the process and mechanisms that ensure the direction, control, and coordination of a blockchain platform to which stakeholders jointly contribute.** This definition aligns well with the research because it provides flexibility in defining blockchain governance. Instead of imposing limitations, it allows governance to be characterized by specific mechanisms.

Once the definition is established, governance mechanisms are investigated. Governance mechanisms are processes, rules and structures that ensure the smooth operation of the consortium. A review of 19 papers identified 19 distinct governance mechanisms as seen in **Table 5.2**, with decision-making, decision rights, and voting being the most frequently mentioned, highlighting their fundamental role in blockchain governance. Incentives and participation rights are also frequently mentioned, as well as addressing stakeholder motivation and inclusion. Accountability, linked with responsibility, is another important mechanism, emphasizing the need to hold parties accountable for their actions within the blockchain platform. Dispute and conflict resolution mechanisms are essential for maintaining the integrity and functionality of the platform, ensuring a fair environment for all parties. **Table 5.2** can be evaluated as a comprehensive toolbox, enabling decision-makers to choose suitable mechanisms and design them to address the identified values. By doing so, the governance design aligns with the values determined by stakeholders. This approach promotes a more integrated and value-driven governance framework.

Additionally, it should be noted that certain governance mechanisms, such as trust, mentioned by Ávila et al. (2022), Hein et al. (2016), and Leewis et al. (2021), and privacy, referenced by Ávila et al. (2022), are not included in the final table presented in **Table 5.2**. The rationale behind this exclusion is that these elements are not perceived as design mechanisms but rather as end goals. The separation underscores the importance of distinguishing between the foundational mechanisms that drive governance and the ultimate objectives that these mechanisms aim to achieve. Trust and privacy are critical outcomes that result from effective governance practices rather than components of governance itself. Ensuring these values are met is vital for fostering a secure and collaborative environment within the blockchain platform.

The research now progresses to its final stage, wherein the eight most critical stakeholder values determined through the Bayesian Best Worst Method are addressed by specific governance mechanisms and potential governance mechanism designs.

6 Value Centric Governance Design Recommendations

6.1. Introduction

The following chapter addresses the final sub-research question:

Sub-Research Question 4: How can governance mechanism designs be developed to ensure the fulfilment of stakeholder values in an aviation part-tracking consortium?

This chapter integrates the findings from sub-research question 2, which identifies the most important values through the BWM as discussed in **chapter 4**, with the governance mechanism designs explored in sub-research question 3 and detailed in **chapter 5**.

The goal of this chapter is to propose one governance design for each stakeholder value aimed at enhancing the participation of aviation stakeholders and ensuring the long-term viability of the data-sharing platform for aviation part tracking. The chapter is structured into subsections, with each subsection dedicated to one stakeholder value. For each value, the most appropriate governance mechanism is identified and thoroughly discussed. The discussion explains why it is considered the most appropriate, detailing how and why the mechanism effectively addresses the value. Once the governance mechanism is established, the potential governance designs within this mechanism are explored and discussed. Among these potential designs, the most suitable one, in light of the presented stakeholder value, has been selected and justified.

Additionally, it is acknowledged that design inherently involves trade-offs. Therefore, selecting a particular design to address one stakeholder's value can have ramifications on other values. This aspect is critically analyzed and discussed as a final component in each subsection. To aid in understanding, each value is visualized through a diagram, illustrating the relationships and trade-offs involved in the governance design choices. In the diagram, a green arrow indicates a positive effect, a red arrow signifies a negative effect, and a yellow arrow denotes a neutral effect. This structured approach ensures a clear and thorough analysis of how each stakeholder value is addressed by governance mechanisms and designs while also considering the broader impact on other values. Before beginning the analysis, a more detailed scoping of values needs to be conducted in **section 6.2** and explained. This ensures that the final governance design is both comprehensive and pragmatic, enabling effective and sustainable blockchain implementation for part tracking in the aviation industry.

6.2. Value Scoping for Governance Design

This chapter explains the governance designs, concentrating on the stakeholder and data contexts. The decision to focus on these two contexts, excluding the blockchain or technology context, is based on the Bayesian Best Worst Method (BWM) result from global weight seen in **Figure 4.3** and credal ranking calculations seen in **Figure 4.4**, which indicate significantly lower importance placed on blockchain technology. This may be because survey participants view technology merely as a tool, suggesting that the issue lies in the design rather than the technology itself.

The analysis further narrows down to the four most important values from both the Data and Stakeholder contexts, a decision validated by the final weights calculated by BWM. Within the Data context, the final weights show a maximum difference of 0.008, indicating no significant disparity among the values. Conversely, in the Stakeholder context, there is a notable drop of 0.03 between the consecutively ranked values of Compliance (4th most important) and Benefit Equality (5th most important). This substantial difference signifies a clear cut-off in importance, justifying the focus on the top four values from each context. So the research continues focusing on the eight most critical values identified through the BWM. These values include Access Control, Confidentiality, Integrity, and Ownership within the Data context. They also encompass Trust, Legitimacy, Neutrality, and Compliance from the Stakeholders' context. The ranking of the top eight values can be seen in **Figure 4.3**

Additionally, while creating governance mechanism designs, sub-values are also taken into account and need to be investigated separately. Among these 8 values, confidentiality, legitimacy and neutrality appear to have sub-values. However, as discussed in **section 4.7**, 6 out of the 12 participants (50%) have placed equal importance on the involvement of authorities and the involvement of regulations, indicating that these two aspects are inseparable and should be discussed together. To proceed, it was decided not to create any governance mechanism design for arbitrage neutrality from the neutrality value due to the substantial sub-local weight difference of 0.18 between the executive (0.39), legislative (0.393) and arbitrage (0.21). This difference indicates that arbitrage neutrality is considerably less important than the values of executive and legislative neutrality. As a result, the focus will be directed towards developing governance mechanisms that prioritize executive and legislative neutrality, ensuring that these more critical aspects are adequately addressed and integrated into the overall governance. This approach aims to enhance the effectiveness and relevance of the governance structures in supporting the consortium's objectives. Finally, due to the credal ranking indicating a confidence level of 0.85 as seen in **Figure 4.6**, there is a strong preference for financial confidentiality over IP confidentiality. Consequently, financial confidentiality is prioritized when creating governance mechanism designs.

Finally, and most importantly, as discussed in **section 5.6**, blockchain consortium governance and mechanism designs are dynamic rather than static. They are not established once and are held constant throughout the entire lifecycle of the consortium. It would be incorrect to assume that the proposed designs are applicable for the consortium's entire lifecycle; instead, they are specifically intended for the formation/design stage of a consortium. While certain design suggestions might seem to contradict the vision of a consortium where all industry members are involved, and data is transparently shared, this remains the ultimate goal. Achieving this end state, however, is not immediately feasible and requires a series of incremental steps and for that reason is left out of the scope of the thesis and thus could be part of further research.

6.3. Data Context Values

The data context highlights the critical importance companies assign to data, viewing it as their primary resource. This context emphasizes stringent data access controls, maintaining data integrity, defining ownership, and ensuring confidentiality to protect sensitive information.

6.3.1. Access Control

Access Control is a value related to the data managed by the platform through its sharing and receiving processes. The primary concern for entities is identifying which specific parties are permitted to access this data.

Several governance mechanisms could address *Access Control*. One option facilitated by blockchain is assigning roles such as developers, miners, or validators to limit data access based on the assigned role. However, relying solely on roles does not fully mitigate the risk, as these roles might be assigned by someone other than the data owner, leading to inconsistencies and errors in enforcing access control policies. Stakeholders prefer to retain control over access decisions themselves to ensure that members with malicious intent cannot misuse their access rights, which could result in data leaks or manipulation.

To address this issue, it is recommended that it be resolved through *system architecture*, thereby maximizing control for the data-holding entity. This approach is based on benchmarking the IBM Food Trust Chain (IBM, 2024a). This involves translating access control policies into code that automates enforcement, ensuring consistent and secure data access. By embedding access controls within the platform, this approach reduces the risk of human error and insider threats. When implementing access control in a blockchain data-sharing consortium, three primary system architecture-based governance mechanisms can be considered: *Role-Based Access Control (RBAC)* (Github, 2022), *Attribute-Based Access Control (ABAC)* (Tuler De Oliveira et al., 2022), and *Discretionary Access Control (DAC)* (Sarfaraz et al., 2023).

First, it should be noted that in all three types of access control, the owner can decide who can access their data. For that reason, the safest method, which guarantees enforcement, should be chosen, prioritizing those with the most detailed and descriptive logs to enable the owner to audit and trust the method.

To start, the most simple method, *DAC*, is investigated. *DAC* allows or limits user access based on an access policy set by the data owner. With *DAC*, each user can control access, granting permissions to others as needed while knowing the identity of the other parties (Sarfaraz et al., 2023). However, this type of access control is not fine-grained. It typically allows access to an entire directory, which means that if someone accidentally adds a confidential file to the wrong directory, everyone with access to that directory can view it. Additionally, revoking access once it has been granted is very difficult. It requires manually adding a new user and revoking the old one, which increases the overhead of manual work. This lack of granularity can lead to unintended data exposure. *DAC*, while simpler, is less capable of handling complex access control requirements and maintaining a high-security posture (Sarfaraz et al., 2023). To mitigate these risks, a more detailed access control system should be implemented, one that allows permissions to be set at the individual file level rather than just at the directory level.

RBAC grants access based on predefined roles and responsibilities within a network. However, it mainly focuses on static organizational roles, lacking the flexibility needed for dynamic access, which limits its adaptability to the evolving platform landscape. Moreover, *RBAC* cannot construct rules using parameters that are unknown to the framework and does not support multi-factor decisions (Coyne & Weil, 2013). While *RBAC* allows for broad access control definitions, *ABAC* offers greater refinement and flexibility.

ABAC within smart contracts offers access based on a collection of attributes such as user type, location, and department, which can provide a more comprehensive access control policy. Research also suggests *ABAC*, as it allows stakeholders to remain anonymous. This means that any combination of personal information (attributes) can be used to identify an individual while protecting their privacy by not including their name. *ABAC* is also more secure than *RBAC* as it combines name, ID number and contextual attributes as part of the policies. *ABAC* is also more suitable for dynamic access control and should be the most adequate solution.

However, as was already noted, every design decision has implications, and using *ABAC* in a blockchain data-sharing consortium offers benefits as well as drawbacks. *ABAC* can easily react to changes within the consortium by dynamically adjusting access controls depending on the characteristics of new or leaving partners, which positively influences *adaptability*. Notwithstanding its advantages, *ABAC's* dynamic and fine-grained characteristics can make it difficult to comprehend and administer, which might make it more difficult for stakeholders to utilize, imposing a negative impact on *ease of use and understandability*. Positively, *ABAC* improves *security* by offering precise access control, making sure that only those with the proper authorization may access critical information depending on certain qualities and contextual circumstances. Because stakeholders may rely on the fairness and dependability of the data access restrictions, the openness and consistency of *ABAC* rules can also help to foster *trust* among them. *ABAC* can be implemented into the blockchain by exploiting smart contracts as suggested by Tuler De Oliveira et al. (2022). The visualization of this can be seen in **Figure 6.1**.

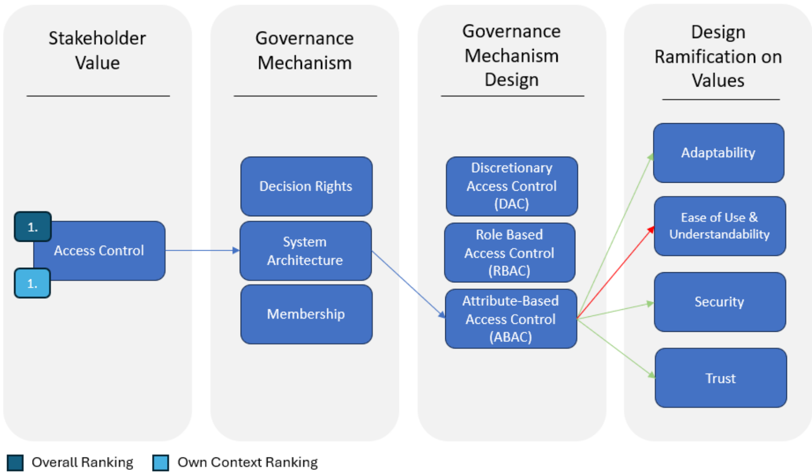


Figure 6.1: Access Control Governance Design

6.3.2. Confidentiality

The *confidentiality* value focuses on safeguarding highly sensitive financial and intellectual property data, including data shared directly and derived indirectly. For example, revealing current inventory levels could enable a competitor to infer the company's inventory planning strategy, thus gaining a competitive edge. Multiple mechanisms can be employed to prevent this. Conducting a *risk management* study is a preliminary step to identify the broader scope of potential issues. Although it does not resolve the problem, it effectively identifies all data that could confer a competitive advantage or be deemed sensitive. Therefore, it is determined that *confidentiality* should be ensured by embedding protective measures within the *system architecture*.

Two options are available to ensure this type of data: *consignment hierarchy* and *off-chain data storage*. The *consignment hierarchy*, benchmarked from the TradeLens project's "*consignment hierarchy*," is adopted from the United Nations Centre for Trade Facilitation and Electronic Business (UN/CEFACT). In this approach, the blockchain data layer is differentiated into three layers: shipment, consignment, and parts. This creates an additional layer within the blockchain for data access. However, as mentioned in interviews, stakeholders prefer not to show or upload data on the chain at all. These solutions are viable if data has to be included on the blockchain. A simpler method again used during the TradeLens and PharmaLedger discussed in **section 5.7** project is *off-chain data handling* (Jovanovic et al., 2022; PharmaLedger, 2024). This involves keeping sensitive financial or IP-related data off the blockchain, recording only necessary references or metadata on-chain. This ensures that only stakeholders with access to the original database can utilize the sensitive data while ensuring transparency.

This governance design is anticipated to positively impact *legitimacy, sustainability, security,* and *adaptability* while exhibiting mixed effects on *trust*. *Legitimacy* is enhanced through regulatory compliance; for instance, the GDPR's right to be forgotten mandates the deletion of entities' data upon request from databases. However, due to blockchain's inherent immutability, data cannot be deleted; it can only be added. So, storing sensitive data off-chain enhances the value of legitimacy. The *sustainability* value also benefits from reduced data volume, resulting in lower carbon emissions. *Security* is strengthened because, in the event of a cyberattack, only the hashes of the data, as an integrity data tool, are compromised, not the highly sensitive information itself. *Adaptability* is improved since sensitive private data does not need to be removed from the chain when a stakeholder exits, thereby reducing barriers to exit. *Trust* is positively and negatively influenced; in the short term, it facilitates easier transitions as stakeholders do not need to provide their data immediately but make it available according to the agreements and regulations. Conversely, it introduces a downside as it requires the involvement of an extra entity responsible for managing access keys, thereby adding another stakeholder to the system and reducing *trust*. The visualization of this can be seen in **Figure 6.2**.

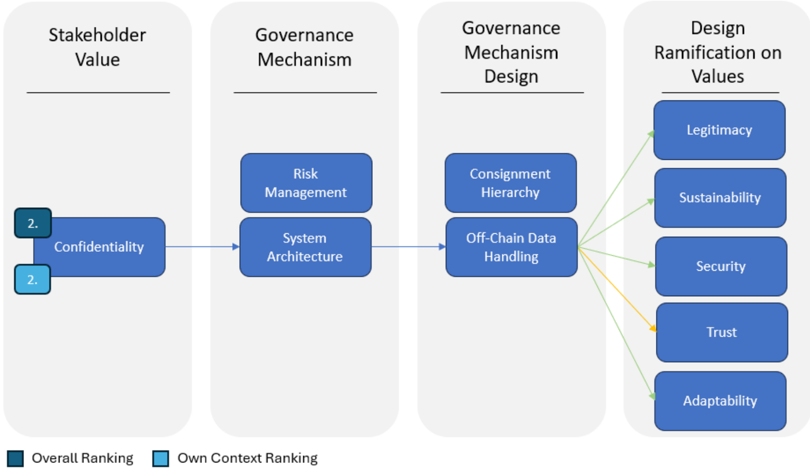


Figure 6.2: Confidentiality Governance Design

6.3.3. Integrity

Data integrity refers to the accuracy, completeness, and quality of data. It can be ensured through governance mechanisms such as *control and monitoring*. Traditionally, third-party oversight has been used to manage audits, but this approach introduces potential errors and misconduct due to corporate interests (ICAEW, 2023). Instead of relying on third parties, validation should be approached through system architecture, emphasizing the consensus mechanism. Robust *consensus mechanisms*, such as those used in blockchain, autonomously verify data integrity, reducing human error and preventing malicious behaviour. For example, without proper integrity measures, data could be altered or deleted, compromising trust. Blockchain helps by using *consensus mechanisms* to secure data and ensuring that policies and standards are consistently applied, maintaining a transparent and immutable record.

In consortium blockchains, several *consensus mechanisms* are commonly applied to ensure data integrity, just like it is used in the case of Port of Antwerp for data authenticity (Port Technology, 2018). Four notable implementations are *Practical Byzantine Fault Tolerance (PBFT)* (Kaashoek et al., 1999), *Ripple Consensus Protocol Algorithm (RCPA)* (Todd, 2015), *HotStuff* (Yin et al., 2019), and *Stellar Consensus Protocol* (Yao et al., 2021). *PBFT*, adopted by Hyperledger under the Linux Foundation, can tolerate up to one-third of faulty nodes, providing robust adversary tolerance. On the other hand, it maintains low latency and high throughput, making it efficient and reliable in smaller networks such as consortiums or private blockchains. *The Ripple Consensus Protocol Algorithm* offers an even stronger adversary tolerance and is designed for fast and efficient consensus. However, it requires that all participants trust unique node lists. *HotStuff*, implemented by Facebook's Libra project, provides a highly scalable and efficient consensus mechanism with linear communication complexity, making it suitable for large networks. Lastly, the *Stellar Consensus Protocol*, used by Stellar, emphasizes low latency and high throughput, using a federated Byzantine agreement system that allows for decentralized control but requires participants to trust a subset of nodes.

Among the various options, *PBFT* is recommended due to its balance of reliability and efficiency, making it an appropriate starting point despite its scalability limitations in larger consortia. This recommendation aligns with a step-by-step approach towards achieving an industry-wide data-sharing platform, beginning with a smaller group and designing accordingly before thinking of the very big picture at the end. It is important to note that selecting a specific consensus protocol has a limited impact on the user interface as it is mainly a background computation algorithm, and the critical aspect lies in ensuring that data integrity is verified through a consensus mechanism rather than by individual stakeholders or entities. This incremental adoption of technological solutions is vital for constructing robust and dependable consortium governance, ultimately paving the way for broader industry-wide data sharing.

However, as mentioned before, each design choice has its own set of implications. *PBFT* positively impacts *tangibility* and *security*, as evidenced by its adoption in mainstream applications like Hyperledger Fabric by similar projects (such as TradeLens), which attests to its proven functionality and high-security standards. It also positively influences *fair value distribution* because it involves tokens, making the distribution of overall financial gains (if that ever happens) easier. Despite these advantages, PBFT has some notable drawbacks. PBFT experiences reduced operational efficiency when the number of nodes becomes too large, leading to potential scalability issues and negatively impacting *growth*. This limitation highlights the trade-offs inherent in choosing a consensus mechanism, where the benefits of security and reliability must be balanced against the need for scalability. The visualization of this can be seen in **Figure 6.3**.

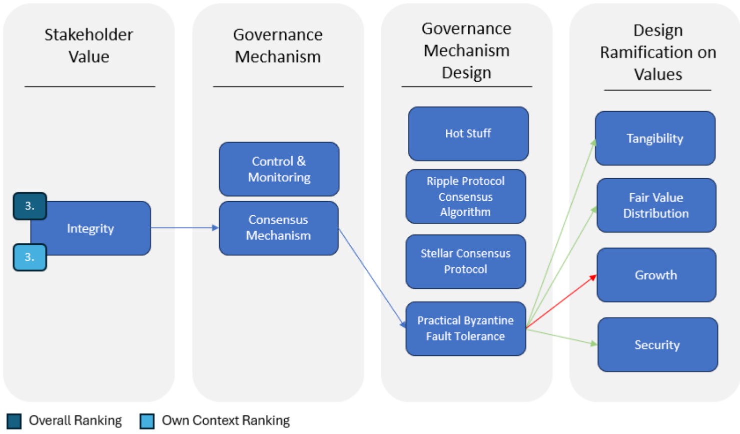


Figure 6.3: Integrity Governance Design

6.3.4. Ownership

These days, data is considered a company's most valuable resource. Data *ownership* is defined as the possession of information that, in return, gives power and competitive advantage. Identifying data *ownership* is essential in data governance, as it clarifies accountability in instances of malpractice and establishes explicit rights, such as copyright, in cases where benefits are generated. However, several issues need to be resolved. Data being an intangible asset in itself, it can be further sold in its original form or resold as a value-added service without even the original owner's knowledge (Gupta et al., 2022). Secondly, data related to a tangible asset complicates matters further. For example, when an engine is sold from KLM to Lufthansa, the physical item is paid for.

Currently, there is no specific mechanism that can ensure or validate *ownership* within the blockchain platform, and even further, there is no unanimously agreed definition for *ownership* of data. The requirements, as per law, are extremely variable regarding data protection. For instance, a report was published in 2016 by the European Commission entitled "Data Protection and Data Ownership" in a bid to point out orderly clearing of these aspects within the European Union. It reviewed the legal positions of various countries: for example, Germany giving "ownership-like rights to a data holder," and the United Kingdom having "no statutory basis for the protection of data itself, and thus no property rights exist; data cannot be stolen, assigned, or inherited (Bertram & Georg, 2018). Bertram and Georg (2018) defines *ownership* as giving individuals the ability to grant and revoke access to their identifying information, indicating the multi-perspective approaches taken to identify *ownership*. Additionally, the European Union Aviation Safety Agency (EASA) has initiated its own Data4Safety program, which is currently still in the development phase and has not yet produced any concrete conclusions (European Union Aviation Safety Agency, 2024).

While it is generally accepted that platform providers should not possess *ownership* over the data and that data *ownership* should be defined by the initial upload, tracing data once it is shared remains a significant challenge. There have been solutions proposed such as Data ownership Protocol with the usage of tokens (Data61, 2024; Organization, 2024). One research uses watermarking to generate a trusted trade trail for tracking the data *ownership* (Gupta et al., 2022); however, this is done on a public blockchain and not in a private or consortium. However, the legal status of *ownership* still remains ambiguous. Therefore, more research is needed to develop robust mechanisms for identifying and then tracing the legal status of data *ownership* on blockchain networks which has to be initiated by regulators. Addressing this gap is crucial for enhancing data governance and protecting the rights of data owners. Because this initiative should come from regulators no action can be taken yet by the consortium and for that reason, no graph is provided.

6.4. Stakeholder Context Values

The stakeholder context examines the inter-organizational interactions and relationships among entities involved in data sharing. This investigation emphasizes key aspects such as trust, neutrality, legitimacy, and compliance.

6.4.1. Trust

The first and most contradicting value within this context is trust. Although the goal of blockchain technology is to create a decentralized, automated, and zero-trust environment based on code, the initial step towards achieving this goal still relies heavily on mutual trust. *Trust* is paramount among stakeholders and acts as a critical initiator for adoption. Therefore,*trust* should not be addressed by a single governance mechanism but rather through multiple governance mechanisms.

The easiest way to establish *trust* within a consortium is to leverage existing relationships among business partners through a governance mechanism centred on *external relationships*. By capitalizing on long-term personal and business relationships, stakeholders can facilitate a smoother transition into the consortium. For example, existing alliances such as SkyTeam could potentially be used. This approach is also currently applied by IDCA (Independent Data Consortium for Aviation, Independent Data Consortium for Aviation, 2021). This approach builds on the established credibility and reliability of existing partnerships, providing a solid foundation for fostering new inter-organizational *trust*. Consequently, it helps create a more cohesive and cooperative environment for effective data sharing and collaboration within the consortium.

Within the data-sharing platform, the first step involves authentication, where identity verification services ensure that all participants are who they claim to be. This can include *Know Your Customer (KYC)* procedures and other forms of identity verification similar to the IBM FoodTrust initiative as discussed in **section 5.7** (IBM, 2024a). However, knowing each other's identities does not necessarily guarantee *trust*, indicating that a singular mechanism for establishing *trust* is inadequate.

For cases where parties prefer not to engage with entities they do not *trust*, the system architecture can incorporate *multiple channels* into the blockchain, created based on informal off-chain relationships. Entities that already *trust* each other can jointly create a channel that becomes part of the larger blockchain network. While this method allows trusted parties to collaborate more effectively, it can lead to a fragmented data-sharing environment, where different channels share varying sets of data (e.g., Channel A shares X, Y, Z data, but Channel B shares only Z data).

The governance designs used in parallel also have ramifications, including positive effects on *access control* and *adaptability*, as well as a negative effect on *growth* and a mediative effect on *sustainability*. The positive impact of defining rules on *access control* arises because stakeholders can ensure they know the identity of stakeholders and remain separate from entities they do not know or wish to share data with. *Adaptability* is enhanced because having more channels makes it easier for a participant to exit one while still remaining a member of others. However, the negative effect on *growth*is due to the fact that only certain relationships may form, potentially limiting the network's expansion. Data disparity can impact environmental *sustainability*. In case data is stored on-chain (which is far from optimal), fragmented data could lead to duplication and increased data processing, which consumes more energy and elevates the carbon footprint of operations. The visualization of this can be seen in **Figure 6.4**.

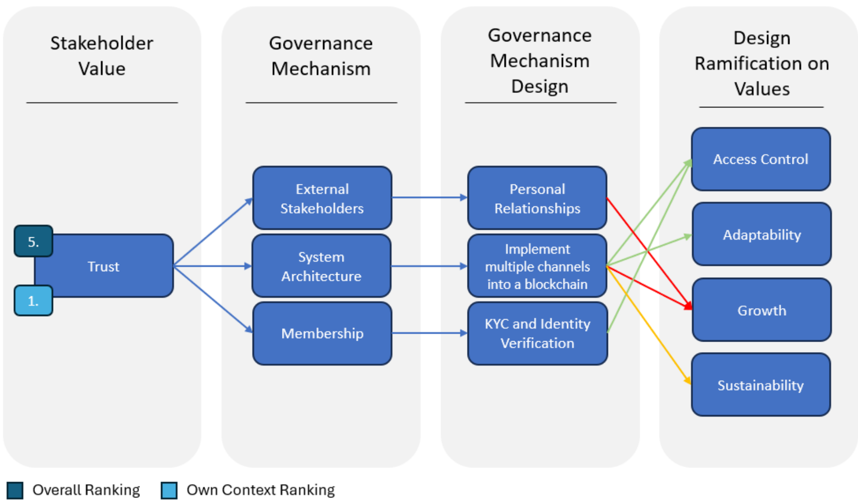


Figure 6.4: Trust Governance Design

6.4.2. Legitimacy

This value pertains to enhancing the credibility of the consortium by incorporating regulatory authorities within the data-sharing consortium.

Several governance mechanisms can be employed to encourage these authorities to join the consortium. The first approach involves offering non-monetary *incentives*. Regulators may be more inclined to join the consortium if they perceive clear benefits, such as streamlined audit processes, a comprehensive overview of operations, and direct access to necessary information without the need for repeated document requests. Additionally, highlighting how data sharing can enhance security measures and strengthen risk management could further incentivize participation. Public organizations such as tax authorities, environmental protection agencies, and public health departments can significantly benefit from access to business data on consortium blockchains or other data-sharing platforms. This access enables more efficient monitoring and regulation, enhances public services, and supports economic development by providing real-time insights into business activities and compliance (Rukanova et al., 2023).

Another strategy involves leveraging *external relationships* to build connections between the platform and existing regulatory bodies. This could include using personal relationships and lobbying efforts to persuade regulators to join. Organizing conferences or events where regulators are present can also be effective. These gatherings provide opportunities to directly communicate the benefits of joining the consortium to regulators and the media, potentially generating public pressure for their involvement.

While no distinct governance designs are specified, the primary objective remains to integrate regulators into the consortium, just like in the Port of Antwerp case where the state sets the standards (Port Technology, 2018). This can be achieved through various governance mechanisms, each aimed at fostering inclusion and demonstrating the consortium's commitment to transparency and compliance.

The involvement of regulators within the consortium significantly boosts its *growth* as the presence of regulatory authorities makes the consortium appear more enduring rather than a fleeting initiative, incentivizing more stakeholders to join. Additionally, the increased credibility leads to better *compliance*, as stakeholders, feeling more supervised, are likely to adhere more strictly to the set rules. Additionally, the participation of regulators raises *awareness* in the heavily regulatory-driven industry about the importance of data sharing. This heightened *awareness* drives more industry players to engage in data-sharing practices, knowing that it aligns with regulatory expectations and enhances operational transparency and they can receive benefits from giving access to their data, e.g. faster customs procedures (Rukanova et al., 2023). Finally, the *neutrality* of the consortium can be enhanced with the involvement of regulators. Their presence ensures that the consortium is not perceived as biased towards any particular group of stakeholders. The visualization of this can be seen in **Figure 6.5**.

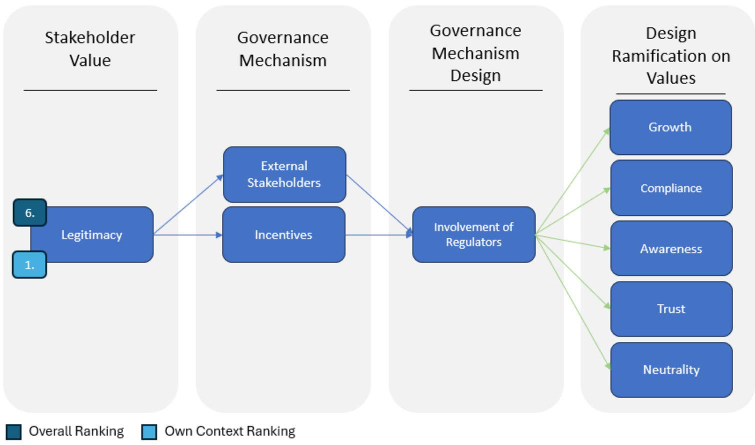


Figure 6.5: Legitimacy Governance Design

6.4.3. Neutrality

To clarify the distinction between *executive* and *legislative neutrality*, consider the traditional separation of powers model, which divides governance into three branches: the legislative (makes the law), the executive (enforces the law), and the judicial (interprets the law). In the context of a data-sharing platform, the governance is similarly divided. *Legislative neutrality* pertains to the body that sets the laws or standards for data sharing across all platforms (e.g., platforms X, Y, Z). *Executive neutrality*, on the other hand, refers to the body that governs a specific platform (e.g., platform X) with its involved entities (e.g., entities A, B, C). *Judicial neutrality* pertains to the impartial resolution of disputes or violations of established rules between parties (e.g., entities A and B).

Executive Neutrality

Executive neutrality, a value concerning the entity that will control a specific platform's direction, is a primary concern for stakeholders. They worry that this executive body might not remain impartial, leading to biased decisions.

There are multiple governance mechanisms that can ensure executive neutrality, one of which is *legal compliance*, where all decisions are based on laws, regulations, industry policies, and standards. However, since data-sharing policies are highly underdeveloped, industry standards and policies cannot yet be taken as a benchmark. Another approach could be *ethical responsibilities*, relying on the greater good of the data-sharing platform and assuming that all participants will adhere to this principle while maintaining the platform. However, this might be overly optimistic in an ecosystem of profit-driven companies. Given that this value primarily revolves around the decisions made by an independent governing body, *decision rights* have been identified as the most suitable governance mechanism.

Based on similar projects like VeChainThor discussed by van Haaren-van Duijn et al. (2022) and PharmaLedger discussed in **section 5.7** PharmaLedger (2024) the four governance designs to consider include: *Ecosystem members led, Service Provider led, Foundation led Independently Governed and finally Foundation led ecosystem governed*.

A graphical representation of all four governance models can be seen in **Figure 6.6**, **Figure 6.7**, **Figure 6.8** and **Figure 6.9**. In *ecosystem-led governance*, members of the network are the ones who govern the network in their collective capacity, with no fixed roles or responsibilities. There is no joint body, hence giving it a neutral perspective because decisions are made jointly by the entire body. In a *service provider-led* model, one service provider governs the network and charges members for the use of its service. *Neutrality* is maintained since decisions are being made by an external party that treats all members like clients. In the *foundation-led*, *independently governed model*, an independent non-profit entity governs the network and creates technology roadmaps and provisioning services. Though members may have some influence, they cannot make these types of decisions.

The last one is the *foundation-led ecosystem-governed model*, where a non-profit foundation is in charge of the direct governance of the network, governed by a board comprising stakeholders in the ecosystem. The foundation directs the network's operations but remains accountable to the stakeholders involved in decision-making. Given the importance of stakeholder involvement collective decision-making and efficiency, the final choice is the *foundation-led ecosystem-governed model*. While the foundation directs operations, this approach ensures that stakeholders participate in and influence decisions, maintaining executive neutrality. Finally, smart contracts can be used to automate enforcement of taken decisions (Tuler De Oliveira et al., 2022).

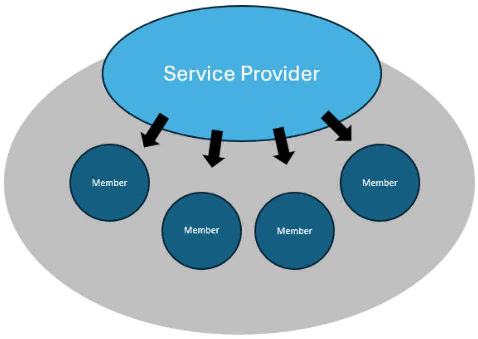


Figure 6.6: Service Provider Led

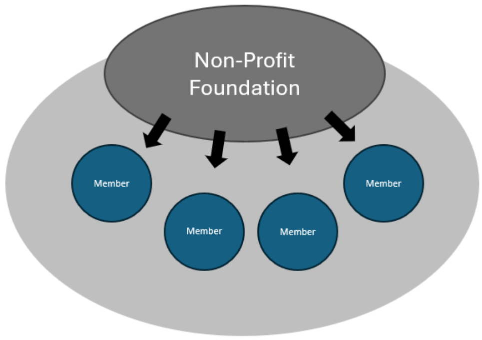


Figure 6.7: Non-Profit Foundation Led

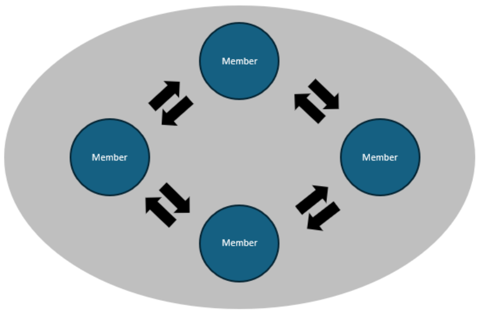


Figure 6.8: Ecosystem Members Led

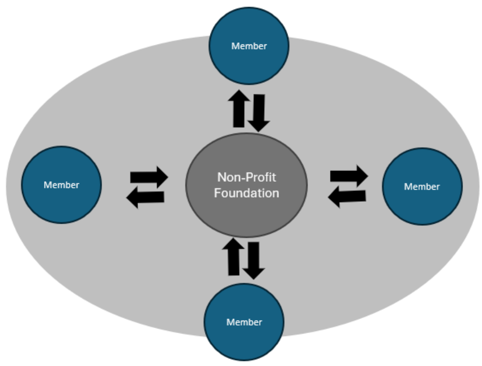


Figure 6.9: Foundation Led Ecosystem Governed

This governance model is anticipated to have a positive impact on *compliance*, *fair value distribution*, and *trust*. The inclusive decision-making process, which involves all members, is likely to enhance *trust* within the platform. By ensuring that all members participate in governance, the created benefits become more transparent, facilitating a more equitable distribution of value. Furthermore, the transparency and inclusiveness inherent in this model are expected to lead to higher levels of *compliance* as members feel more engaged and accountable. One potential downside could be its impact on *growth*, as decision-making involving more stakeholders can become more challenging. This difficulty might lead the existing group to resist adding new entities, which could negatively affect *growth*. The visualization of this can be seen in **Figure 6.10**.

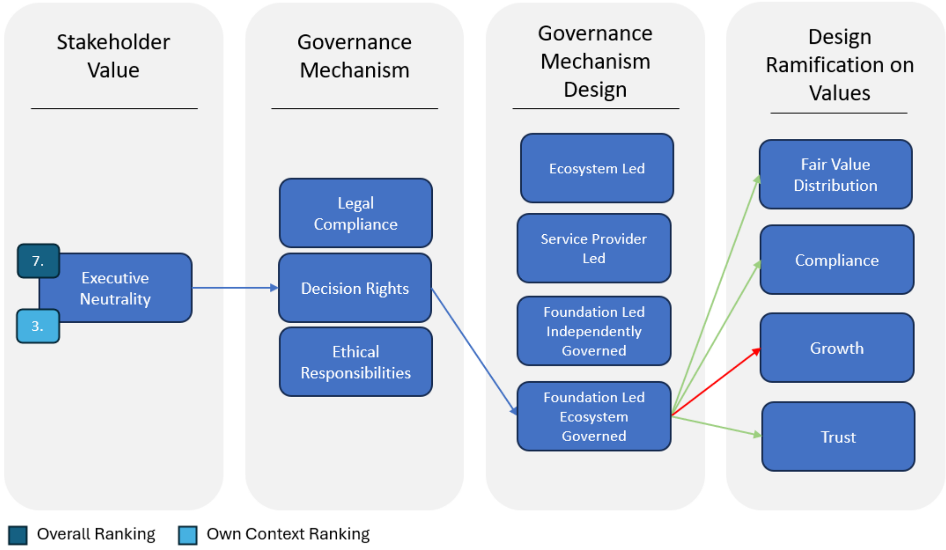


Figure 6.10: Executive Neutrality Governance Design

Legislative Neutrality

Legislative neutrality, a value that focuses on the impartiality and separation of the entity responsible for setting the rules and regulations of data-sharing platforms, is a significant concern for stakeholders. To ensure *legislative neutrality*, several governance mechanisms can be implemented. One such mechanism is *legal compliance*, where all decisions adhere strictly to existing laws and regulations, just like the Port of Antwerp case (Port Technology, 2018). However, given the current underdevelopment of data-sharing policies, industry standards and policies are not yet reliable benchmarks. Therefore, *decision rights* have been identified as the most suitable governance mechanism to uphold *legislative neutrality*. This approach ensures that the decisions made by the governing body are fair, transparent, and reflective of the collective interests of all stakeholders involved.

There are two potential governance designs to consider: an *independently governed advisory council* and a *stakeholder-governed advisory council*. The primary difference between the two is that the former excludes stakeholders directly involved in data sharing within their organizations from rule-making, while the latter includes them.

At first sight, involving stakeholders in rule-making may seem beneficial due to their vested interests in data sharing. However, this approach operates at a higher legislative level where broader public interests and general regulations must be considered. Stakeholders primarily focused on profit-making may engage in lobbying and possess a limited perspective on the legislative landscape, potentially leading to biased or self-serving rules.

Therefore, an independently governed body is recommended. This body should be composed of experienced individuals from the aviation industry, researchers, and rule-makers who can provide a more balanced and comprehensive view. These experts can ensure that the legislative framework is developed with the greater good in mind, free from the influence of profit-driven entities.

This decision positively impacts *benefit equality* by establishing clear value-creation rules and addressing current confusion. Industry-wide *compliance* becomes easier as platforms no longer need to develop individual regulations. *Growth* is enhanced by attracting stakeholders through neutral rule-making. *Legitimacy* increases with regulator involvement, ensuring credible and enforceable rules. *Trust* is enhanced due to the impartiality of the governing entity, fostering a reliable environment for data sharing. A visualization of this can be seen in **Figure 6.11**.

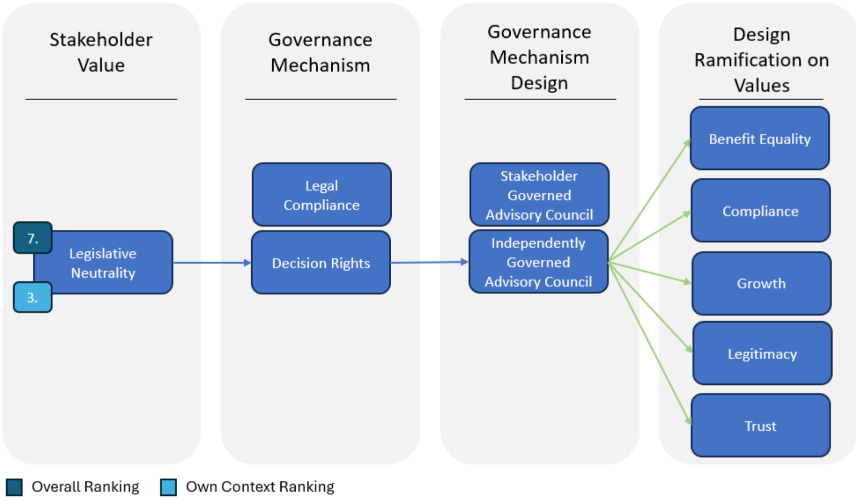


Figure 6.11: Legislative Neutrality Governance Design

6.4.4. Compliance

Compliance refers to the value described by adhering to the predetermined laws or rules of the consortium.

Several governance mechanisms can address *compliance* effectively. One option is *control and monitoring*. Random audits conducted by independent third parties not involved in the blockchain platform can significantly ensure that participants adhere to established rules and standards. These audits provide an objective assessment of *compliance* and can help identify any discrepancies or areas for improvement. However, the involvement of these parties is prone to errors, which could undermine the reliability of the audits.

Another mechanism, namely dispute resolution or, more specifically, *sanctions*, can be implemented for misconduct as mentioned by (Akgiray, 2018; De Filippi & Loveluck, 2016; Greiner et al., 2024; van Haaren-van Duijn et al., 2022; Ziolkowski et al., 2019). This approach serves as a deterrent against non-compliance, as the threat of significant penalties can encourage participants to adhere to the rules. Sanctions can include fines, suspension of membership, or even expulsion from the consortium.

During interviews, stakeholders were asked, "So you have mentioned the value of *compliance*. How do you think processes or arrangements should be addressed?" Only one stakeholder provided a valid response, stating:

"[...] If you talk about compliance, then you also have to be careful about it because it's easy to punish organizations that are misbehaving. Or, you know, expelling them from the consortium. That is the natural thought of many people. If you do something wrong, then you have to punish the organization. The thing is, you really have to be very, very careful with that. Typically, then, the mistakes being made and also in the *** industry (the prior industry they worked in), I saw that you have to consider misbehaviour in the eyes of the community, not so much as being bad, but having an educational problem. You should assume that the application of the rules is not understood by certain organizations in the way, and it should be so as a consortium, you have to help Members and provide the right knowledge to follow the rules."

This perspective offers a refreshing view, proposing that *compliance* should not be seen merely as a mechanism of control and punishment. Instead, it emphasizes the importance of fostering understanding and education. Communication should, therefore, be the primary tool for achieving *compliance*. By utilizing workshops, comprehensive *compliance* manuals, and engaging webinars, organizations can promote a culture of *compliance* through education rather than enforcement. Such a governance approach not only enhances *compliance* but also positively impacts *awareness* and *trust* among stakeholders. A visualization of this can be seen in **Figure 6.12**.

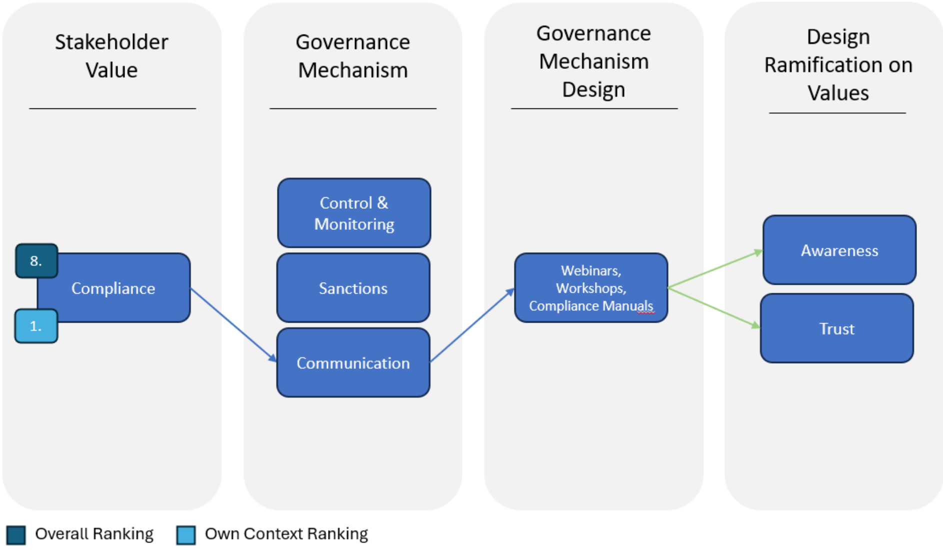


Figure 6.12: Compliance Governance Design

6.4.5. Final Governance Design & Discussion

The visualization presented in **Figure 6.13** synthesizes the nine governance aspects identified as critical by stakeholders. Of these nine aspects, four pertain to the data context, while five are related to the stakeholder context. Design proposals have been developed and integrated for eight of these values. However, it is important to note that the legal status of data ownership remains a matter beyond the stakeholders' jurisdiction and requires resolution by relevant authorities. Consequently, this aspect is deliberately excluded from the consortium governance design framework.

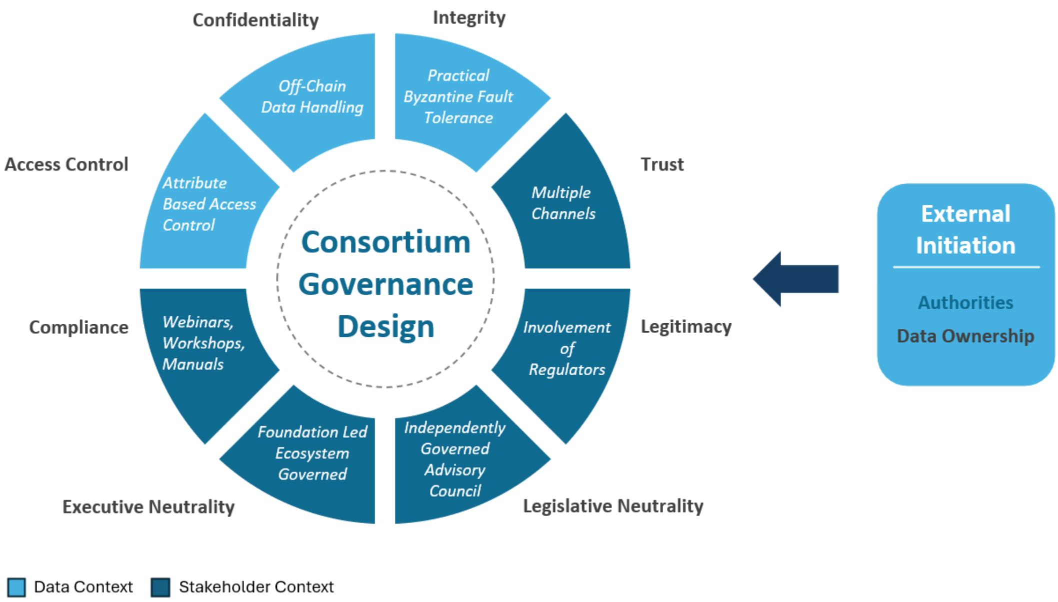


Figure 6.13: Final Governance Design Visualization

The research, which initially set out with a focus on blockchain technology and aimed to develop design requirements centered around it, has ultimately identified eight key design requirements. Of these, four can be effectively addressed through the implementation of blockchain solutions. However, the remaining four requirements cannot currently be resolved through technological means alone and continue to rely heavily on human intervention. This outcome is not unexpected, as the stakeholder context inherently emphasizes the importance of interpersonal interactions and collaboration among stakeholders.

Thus, it can be concluded that while blockchain technology offers promising solutions for specific stakeholder values of the design requirements, it is not the solution for all. The technology is well-suited to addressing challenges related to data security, transparency, and decentralization. However, the complex dynamics of stakeholder relationships, which involve negotiation, trust-building, and consensus, still require human engagement and cannot be entirely automated or managed by technology alone. This highlights the need for a balanced approach that integrates both technological and human-centred strategies to address the full spectrum of governance challenges identified in the research.

Additionally, this research highlights that although blockchain technology has been proven to effectively resolve certain challenges, critical issues and limitations remain that cannot be fully addressed by technology alone. Intellectual property (IP) management, for instance, remains a particularly complex issue that cannot be entirely resolved through blockchain. Addressing the challenge of IP management within a decentralized framework requires further research and innovative approaches. Recent studies suggest that a combination of artificial intelligence and federated learning can be applied, which ensures data decentralization while maintaining the intellectual property (Ma et al., 2024).

Design Conflicts

To design an effective solution, it is essential first to understand the underlying values. Once these values are clearly defined, a tailored solution can be developed. Following this, it is necessary to evaluate potential conditions and challenges, ensuring that any required mitigating actions are implemented. The final design must be both feasible and aligned with the identified core values. To ensure a thorough evaluation, a design conflict analysis was conducted, resulting in **Table 6.1** In the table, an 'O' signifies that no significant conflict is anticipated, while an 'X' indicates a potential conflict that requires careful mitigation or management.

Governance Design	Attribute Based Access Control	Off-chain Data Handeling	Practical Byzantine Fault Tolerance	Multiple Channel Implementation	Involvement of Regulators	Independently Governed Advisory Council	Foundation Led Ecosystem Governed	Webinars, Workshops
Attribute Based Access Control		x	o	o	o	o	o	o
Off-chain Data Handeling			o	o	x	o	o	o
Practical Byzantine Fault Tolerance				o	o	o	o	o
Multiple Channel Implementation					o	o	x	o
Involvement of Regulators						o	o	o
Independently Governed Advisory Council							o	o
Foundation Led Ecosystem Governed								o
Webinars, Workshops								

Table 6.1: Design Conflicts based on Value Reccomendatitions

Synchronizing ABAC policies across on-chain smart contracts and off-chain systems is challenging due to the risk of inconsistencies when policies are updated. A centralized policy management approach, where a unified repository maintains ABAC policies, can help mitigate this risk. To ensure consistency, both on-chain and off-chain systems should reference this repository. Whenever a policy is updated, the change should be propagated instantly to all relevant systems. Utilizing a distributed database or a blockchain-based solution for this repository can further enhance synchronization, ensuring that both environments enforce the most current policies, thus reducing the risk of outdated access controls.

When addressing compliance regulations in relation to off-chain data, it becomes clear that without a clear method for regulatory bodies to access encrypted data stored outside the blockchain, neither objective can be effectively achieved. A crucial component missing from this framework is the management of encryption keys—specifically, how these keys should be handled and provided to regulatory bodies to enable access to off-chain data. While a straightforward solution might exist to mitigate this issue, it is important to note that blockchain technology alone does not offer a built-in mechanism for this purpose. Therefore, additional tools or systems are required to make such access possible, ensuring compliance while maintaining the integrity of the encrypted data.

A foundation-led ecosystem governed by the implementation of multiple channels can lead to challenges such as inconsistent policy enforcement across these channels. This inconsistency can result in varying interpretations and applications of policies, potentially undermining the overall governance structure. Additionally, the existence of multiple channels may encourage the formation of groups or factions within the ecosystem, further complicating coordination and collaboration efforts and potentially leading to conflicts or fragmentation within the community.

6.5. Conclusion

This chapter answers the fourth and final sub-research question.

Sub-Research Question 4: How can governance mechanism designs be developed to ensure the fulfilment of stakeholder values in an aviation part-tracking consortium?

This chapter's analysis is narrowed down to eight key values, four of which are from the data and stakeholder contexts. For the data context, these include **Access Control, Confidentiality, Integrity, and Ownership**, while the stakeholder context values are **Trust, Legitimacy, Neutrality, and Compliance** based on the Bayesian Best Worst Method results.

Each of these values is addressed through specific governance mechanisms and governance design. For example, **access control** is managed via a **system architecture** mechanism that utilizes **attribute-based control** enforced through smart contracts on the blockchain. This ensures that stakeholders maintain **access control**, offering granular control and enhancing data governance. Furthermore, it is recognized that design inherently involves trade-offs between values. Consequently, choosing a specific design to address one stakeholder's value may impact other values. In this case, the granularity of **access control** introduces additional complexity, potentially impacting **ease of use** and **understandability**, which is another identified value. Although this trade-off is less critical since **ease of use** is ranked low in importance, it highlights the need to consider the effects on other values when designing governance mechanisms to ensure their overall viability. This approach is applied to all eight values identified through BWM.

From this perspective, two key conclusions can be drawn. Firstly, it is evident that there is no universally optimal governance mechanism design that enhances stakeholder participation; instead, this design must be tailored to the specific values held by stakeholders within their unique contexts. As these values are context-dependent and may evolve over time, it is crucial for decision-makers to start by thoroughly investigating stakeholder values.

Secondly, it should be emphasized that blockchain governance mechanism designs are inherently dynamic. The recommendations provided are intended for the initial formation stage and are not meant to apply uniformly throughout the entire lifecycle of the system. While some design suggestions may appear contradictory, they are essential for facilitating gradual progress toward the desired end state. This adaptive approach ensures that the governance mechanism can evolve in response to changing stakeholder values and contextual needs.

7 Conclusion & Discussion

7.1. Introduction

In this chapter, the research findings are summarized. The chapter starts by outlining the limitations of the study in **section 7.2** and continues highlighting the key insights from each sub-question in **section 7.3** that collectively address the main research question. Subsequently, the scientific contributions and societal relevance of the research are discussed in **section 7.4** and **section 7.5**. The chapter continues by discussing potential further research in **section 7.6**. Finally, relevant courses from the Management of Technology (MOT) program are explained in **section 7.7**.

7.2. Discussion & Limitations

The primary limitation stems from the research's very context-dependent exploratory nature. Part-tracking within aviation is a very niche context where blockchain data-sharing consortia are either not yet established or are in the initial stages of establishment. This could potentially lead to the oversight of certain values that may become evident once these consortia are fully established while also overlooking the broader perspective of values in general.

The second bias pertains to the interviews conducted, where judgment sampling was employed to select stakeholders. Given that participants had prior involvement with blockchain technology, one could argue that this sampling method may have introduced an unintended positive bias. Efforts to mitigate this bias included specifically asking, "What aspect of blockchain technology makes you most uncomfortable during implementation or usage, and why?" This critical inquiry aims to address potential biases, although its effectiveness remains open to debate.

Another significant aspect of the interviews was the inability to interview the specific stakeholder group of regulators. Instead, an industry expert with 30 years of experience was interviewed, raising questions about the adequacy of regulator representation. Due to the limited number of researchers involved, the coding process for the interviews was conducted in a single cycle. This constraint may have impacted the depth and reliability of the coding process.

An additional limitation of the survey is its extensive nature of 20-25 minutes, which presents several concerns. Firstly, the survey's length may contribute to respondent fatigue, potentially causing participants to feel overwhelmed or lose focus, resulting in rushed or incomplete responses. Additionally, the considerable duration of the survey may deter individuals from participating, as it may be perceived as excessively time-consuming. Furthermore, five stakeholder groups (OEM, disposer, regulator, pool provider, and lessee) were each represented by only one stakeholder. This raises questions about the generalizability of the results for each group.

Consequently, a decision was made to omit the environmental context of the TOE framework, which emphasizes the regulatory landscape and industry structure, from the literature review in order to concentrate specifically on data-sharing solutions. Within the aviation industry, which is highly conservative and predominantly driven by regulatory requirements, this exclusion could potentially affect the ranking of values of stakeholders in the aviation industry.

Additionally, a critique regarding the final output of the value layers as seen in **Figure 4.1** is the potential inclusion of additional data values such as Nonrepudiation and Auditability. Nonrepudiation ensures that stakeholders cannot deny their actions, while Auditability requires that for every action, it must be possible to determine who performed it, as well as when, where, why, and how it occurred, as studied by Tuler de Oliveira et al. (2022). However, these values do not appear in the initial research because the reference paper is not a consortium study and was only discovered after the survey was distributed. Consequently, no adjustments could be made to include these values.

Finally, when considering the design of governance mechanisms with a more neutral stance on the underlying values, it becomes essential to reflect on the potential biases introduced by initially framing the research with blockchain technology in mind. The decision to focus on blockchain as the foundational technology may have inadvertently shaped the values and priorities identified during the research process. This raises the question of whether other values, which may be equally or more relevant in different technological contexts, were overlooked simply because they do not align as closely with blockchain's characteristics. To conclude while it is reasonable to have developed governance mechanisms with blockchain in mind, given that it was the focal technology of the research, it is equally important to critically assess whether these mechanisms remain relevant and consistent if alternative technologies were to be considered. This reflection ensures that the governance designs are not only well-aligned with blockchain but are also flexible enough to accommodate other technologies that might be relevant in future contexts.

7.3. Key Findings by Revisiting Sub-Research Questions

With the increasing complexity of data sharing in the aviation industry and shrinking profit margins, companies are seeking new methods to share data more efficiently and explore opportunities to remain competitive. Various solutions have been explored to address these challenges, with data-sharing platforms showing great potential to mitigate the identified issues. Specifically, blockchain technology has been studied in multiple industries and projects for these data-sharing platforms. However, these initiatives have not been widely adopted by stakeholders within the industry due to the lack of proper governance of the platform, which hinders participation. To address this gap, the main research question of this thesis is:

Main RQ: How can governance mechanisms be designed to enhance participation in blockchain-based aviation part-tracking consortia?

An analysis of the lifecycle of an aircraft part led to the identification of the eight stakeholders (Original Equipment Manufacturer, Tier 1 Supplier, Regulator, Lessor, Operator, Maintenance Repair and Overhaul, Pool Provider and Disposer) actively involved in different stages of the part's lifecycle leading to first sub-research question.

SQ1: What governance values do stakeholders have for participating in a Blockchain aviation part tracking consortium?

The widely recognized Technology-Organization-Environment (TOE) framework was utilized in the study to investigate blockchain adoption in consortium data sharing. During research, it was recognized that the environmental context, including laws and regulations, is highly significant. However, it was excluded to allow for a more in-depth analysis of perceptions related to data-sharing solutions. Consequently, the thesis shifted its focus to the technological and organizational components, identifying seven values within the technology context and six within the organizational context. The organizational context was further expanded to include inter-organizational aspects, recognizing the necessity of examining the relationships and interactions between stakeholders utilizing data-sharing platforms.

As a result, the framework evolved from the Technology-Organization-Environment (TOE) model to a Blockchain-Stakeholder-Data (BSD) framework. This new framework reorients the focus towards blockchain aspects, stakeholder interactions, and the data context.

Contact was established with the Independent Data Consortium for Aviation (IDCA) for the identification of stakeholder values. The researcher engaged in participatory observations within their part-tracking work group and conducted interviews with eight high-level executives from the aviation industry. The findings from the three methods (literature review, participatory observations, and interviews) resulted in the identification of 21 values and 11 sub-values across the three contexts.

However, designing a system that accommodates 21 values and 11 sub-values is practically unfeasible. Furthermore, it could be expected that not all values hold equal importance, necessitating the prioritization of certain values over others. Therefore, it is essential to prioritize the identified contexts, values and sub-values.

SQ2:What are the critical values of stakeholders for designing governance mechanisms?

The Best Worst Method (BWM) established by Rezaei (2020) is adopted. A questionnaire by using prior TU Delft master thesis (Lanzini, 2020; Lopes Vieira, 2022) was developed using Qualtrics Survey Software, asking respondents to select the most and least important values. They were then asked to compare the most important value to the others and the least important value to the others. Ultimately, 12 responses were received, yielding a response rate of 13.3% which is an acceptable number for analyzing a BWM survey (Rezaei, 2020).

The analysis began with examining the context for the overall population of stakeholders, revealing that **data** is the most critical context, with a significance score of 0.4496. This underscores its importance as a fundamental asset for their companies. **Stakeholder** context ranks second with a score of 0.3454, highlighting the importance of the participant network within the consortium. A final value of 0.205 for blockchain explains that it is primarily viewed as a means for data sharing rather than the main focus. The high importance placed on data is reflected in the 4 top-ranked values, which include accessibility control, confidentiality (particularly financial confidentiality) and finally, integrity and ownership.

Within the stakeholder's context, the four most important values are trust, legitimacy, neutrality and compliance. Trust is foundational to all interactions, even though the ultimate goal is to create a trustless environment by adopting blockchain technology. Establishing trust is the initial step towards this objective. Following trust, legitimacy is crucial, which was also discussed during the two-day workgroups, emphasising that the involvement of regulators can significantly enhance legitimacy. This increased legitimacy is expected to have a positive impact on growth by convincing more entities to join the consortium. The third value, neutrality, is also of great importance. It was a primary reason for the establishment of the IDCA, which positions itself as a legislative entity. However, stakeholders have expressed a desire for not only legislative but also executive neutrality. This suggests that stakeholders value an impartial approach in both rule-making and execution. Additionally, the a relatively lower importance placed on neutrality in arbitration. Finally, compliance ranks as the fourth most important value, indicating that stakeholders must adhere to the rules established within the platform.

Within the blockchain context, security against malicious attacks is the top priority for stakeholders, followed by adaptability and tangibility, which indicates a focus on both immediate protection and long-term functionality of the blockchain. Interestingly, sustainability ranks lower, suggesting that immediate operational concerns take precedence over environmental considerations within the data-sharing consortium. Ease of use and understandability are the least important values, likely due to the current focus on establishing and securing the blockchain platform. However, as previously mentioned, since the blockchain context is ranked as the least important and the precedence of data and stakeholders' contexts is validated by credal ranking, it is not further investigated within this thesis.

The most important values have now been identified, directing the research towards ensuring that these values are fulfilled. To achieve this, the study poses the following sub-research questions.

SQ3:How are governance mechanisms currently designed within the blockchain consortiums?

The sub-research question commences by reiterating the necessity of blockchain governance, illustrated through real-world examples. The review of these 19 papers reveals that 11 (58%) provide explicit definitions of blockchain governance, while 8 (42%) describe it through various governance mechanisms without offering a specific definition. This analysis underscores the diversity and varying interpretations of blockchain governance. The ultimate definition formulated for this research is: **Consortium blockchain governance refers to the process and mechanisms that ensure the direction, control, and coordination of a blockchain platform to which stakeholders jointly contribute.** This definition aligns well with the research because it provides flexibility in defining blockchain governance. Instead of imposing limitations, it allows governance to be characterized by specific mechanisms.

Once the definition is established, governance mechanisms are investigated and summarized in **Table 5.2**. This table serves as a practical toolbox, enabling decision-makers to choose suitable mechanisms and design them to address the identified values.

A critical finding from investigating these mechanisms is the recognition that consortium governance should not be viewed as static but rather as dynamic. This dynamic perspective emphasizes the evolving nature of blockchain platforms, incorporating mechanisms that facilitate adaptation and change over time. This approach considers different lifecycle stages, such as formation, operation, and crisis management. Therefore, stakeholders must understand that governance decisions need to evolve in accordance with the increasing involvement of stakeholders and the project's changing phases. Finally, existing blockchain projects are analyzed (IBM FoodTrust, Port of Antwerp, PharmaLedger, VeChainThor, and TradeLens). This investigation aims to provide recommendations for the identified values, not only at the higher level of mechanisms but also through directly applicable design decisions.

SQ4:How can governance mechanism designs be developed to ensure the fulfilment of stakeholder values in an aviation part-tracking consortium?

The analysis concentrates on the four most critical values from both contexts: Access Control, Confidentiality, Integrity, and Ownership (Data context) and Trust, Legitimacy, Neutrality, and Compliance (Stakeholder context). A governance design is suggested for these values. Lastly, the trade-offs resulting from governance designs impacting these values are critically examined, supported by visual diagrams that illustrate these relationships.

Access control is managed via a system architecture mechanism that utilizes attribute-based control enforced through smart contracts on the blockchain. This ensures that stakeholders maintain access control, offering granular control and enhancing data governance. Furthermore, it is recognized that design inherently involves trade-offs. Consequently, choosing a specific design to address one stakeholder's value may impact other values. In this case, the granularity of access control introduces additional complexity, potentially impacting ease of use and understandability, which is another identified value. Although this trade-off is less critical since ease of use is ranked low in importance, it highlights the need to consider the effects on other values when designing governance mechanisms to ensure their overall viability.

In conclusion, by addressing these sub-questions, the main research objective is fulfilled, which is structuring blockchain governance arrangements that optimize participation in the data-sharing consortium. **It is important to note that there is no universally accepted governance mechanism design guaranteed to enhance stakeholder participation; the effectiveness of such mechanisms depends on the specific context. Stakeholders can adopt a value-centric design thinking approach, ensuring they interact with the stakeholders with whom they will share data. By designing governance mechanisms that align with and fulfil these values, stakeholders can promote enhanced participation in the consortium. This approach emphasizes the importance of context-specific solutions and stakeholder engagement to create effective**

and participatory governance structures.

Finally, an unexpected finding emerged during the interviews when questions regarding potential conflicts between opposing parties were raised. A few interviewees expressed surprise at the inquiry, as the notion of alternative approaches to designing such collaborations had not been previously considered. This reaction can be attributed to the industry's intense focus on profit margins, which are often razor-thin, coupled with the slow pace of industry development. There appears to be an ingrained belief among many participants that successful collaboration would be difficult, if not impossible, to achieve. Additionally, there was a noticeable struggle to empathize with the perspectives of opposing parties. Despite these challenges, the necessity of effective collaboration to meet client demands remains paramount. It was particularly surprising to discover that, even under these circumstances, a common ground could be identified.

7.4. Scientific Contribution

The primary scientific contribution of this thesis lies in its novel approach to governance mechanisms by prioritizing stakeholder values, a perspective overlooked in existing research by Ávila et al. (2022), Carter (2018), De Filippi and Loveluck (2016), Gasser et al. (2015), Leewis et al. (2021), Pelt et al. (2020), Rukanova et al. (2023), and van Engelenburg et al. (2020), who have focused solely on governance mechanisms. This thesis demonstrates that effective governance design must begin with a thorough understanding of stakeholder values. By identifying and understanding these values first and then mapping them to appropriate governance mechanisms, the study ensures that the governance design aligns with stakeholder values. This structured methodology enhances the likelihood of successful implementation and acceptance of governance structures.

To the best of the author's knowledge, and as evidenced in **Table 3.2**, blockchain consortiums have never been studied within the aviation industry. This pioneering exploration contributes significantly to the body of research by introducing blockchain governance mechanisms to aviation. The study not only fills a critical research gap but also could serve as a validation tool for the findings from other industries.

The selection of the data to be shared and received by stakeholders emerged as the most important context for joining a consortium. This finding illustrates that current technology acceptance models and data-driven technologies cannot be effectively analyzed without considering the specific context of data exchange. Consequently, any analysis of technology acceptance must account for the nuances of data sharing and its impact on stakeholder engagement and collaboration (Zhong & Moon, 2023).

7.5. Societal Relevance

This report's significance extends beyond its scientific implications. It offers substantial social benefits that can be applied in three principal ways to enhance the effectiveness of data-sharing consortiums.

Firstly, the report underscores the importance of understanding stakeholder values and incorporating them into the design process. This approach is pivotal for fostering mutual understanding among consortium members. By taking these values into account, stakeholders can gain a deeper appreciation of each other's viewpoints and priorities, promoting more harmonious and effective collaboration. This enriched mutual understanding leads to improved decision-making processes, more efficient conflict resolution, and the creation of a more inclusive and supportive consortium environment.

Additionally, the **chapter 5** of the report, noted for its conciseness, serves as a valuable summary for ongoing data-sharing consortiums. This chapter provides insights from previous blockchain consortiums and is a benchmarking guide for current projects, which may lack direct access to all relevant literature. By summarizing governance mechanism designs, this chapter helps consortiums avoid past mistakes and adopt best practices. Furthermore, it offers a 'mechanism toolbox' that stakeholders can utilize directly. Stakeholders can review the table and select appropriate governance mechanisms by identifying relevant values, facilitating immediate application and enhancing the consortium's operational efficiency.

Lastly, the suggested designs, derived from stakeholder values, can be directly implemented for the aviation part-tracking consortium, thus streamlining the decision-making process and enhancing the consortium's effectiveness. These designs provide actionable steps that consortium members can adopt immediately, reducing the time and effort required for consensus-building and implementation. By aligning these strategies with the expressed values and needs of stakeholders, the consortium ensures that its initiatives are more relevant, impactful, and widely supported.

For the initial phase of implementation, it is advisable to engage regulators to establish credibility, thereby fostering increased participation. Once a stable level of participation is achieved, the focus can then shift to examining the values of the stakeholders involved. However, it is important to acknowledge potential implementation challenges, including technical limitations, monetary resource constraints, and the necessity for ongoing stakeholder engagement to ensure that adopted strategies continue to align with evolving values and needs. Proactively addressing these challenges will be essential for successfully realising the report's recommendations and the sustained effectiveness of the consortium.

7.6. Future Research Recommendations

Future research should focus on assessing the applicability of the identified values and governance mechanisms across different industries and contexts, addressing the question: How do these mechanisms and values vary in their effectiveness and relevance across different sectors beyond the aviation industry's MRO context? To achieve this, researchers could employ a combination of comparative case studies, cross-industry surveys, and longitudinal studies to quantify the impact of these governance mechanisms in diverse settings.

While this research acknowledges the importance of a dynamic view of consortiums, it was unable to fully integrate this perspective due to resource and time limitations. However, conducting a longitudinal study that examines the lifecycle of a data-sharing consortium and the evolving values of its stakeholders presents a valuable research opportunity. Such a study would provide deeper insights into how stakeholder priorities shift over time and how governance mechanisms need to adapt to these changes. Key publications to follow-up on would be Laatikainen et al. (2021) and van Haaren-van Duijn et al. (2022).

Additionally, the survey results indicated a significant difference in the importance of Arbitration neutrality and executive-legislative neutrality. This disparity warrants further investigation to uncover the reasons behind these preferences.

Furthermore, broadening the survey to encompass a larger and more diverse group of respondents will help identify which stakeholders prioritize particular values and which governance mechanisms meet those values. In theory, this research can pinpoint the mechanisms likely to cause conflicts, thereby revealing the stakeholders who may be at odds. By examining these potential conflicts, researchers can devise strategies to alleviate them, promoting more effective governance.

Moreover, since a single value, such as access control, can be addressed by multiple governance mechanisms, it is essential to explore how these overlapping mechanisms interact and impact each other. Understanding these interactions will provide insights into the future evolution of values within the organization and inform the creation of governance strategies that accommodate the diverse interests of stakeholders. This approach will ultimately enhance the overall efficiency and harmony within the governance structure.

7.7. Relevant MOT Program Courses

In the preparation of this Master's Thesis, knowledge from several courses within the Management of Technology program has been utilized. The course "Emerging and Breakthrough Technologies" offered valuable insights into technology diffusion and acceptance. It emphasized that technology push alone is insufficient for a successful innovative project; appropriate organizational and environmental elements are also necessary, which this research explores through consortium dynamics. The course "Inter and Intra Decision Making" provided critical insights into stakeholder values and consortium formation, aiding in creating design trade-offs in the decision process. The course "Research Methods" offered a comprehensive understanding of the steps required to design and conduct scientific research. Lastly, the course "Preparation for Master Thesis" supplied the necessary theoretical foundation for interview coding and analysis.

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A Appendix A - Background Information

A.1. Blockchain Technology in Aviation Industry Different Use Cases

- **Customer Loyalty Programs:** Programs built for providing financial incentives to frequent users. While loyalty programs might be seen as a non-target for hackers, it is noteworthy that 11% of data theft attacks in 2017 were directed at loyalty accounts (Ahmad et al., 2021b). The existing issues with these programs are threefold: susceptibility to cyberattacks, a significant portion of travellers (36%) failing to redeem their rewards due to complex redemption processes, and rewards expiring over time. Blockchain technology presents a viable solution to these challenges by leveraging cryptographic methods, and 'unscribable' tokens. (Antoniadis et al., 2019; Kumar et al., 2019)
- **Crew Certification:** Certifications proving that the crew onboard is adequately trained and equipped to ensure passenger safety. Due to the centralized data management system of operators, these certificates can get lost or faked by malicious individuals. Digitizing these certifications on a blockchain would facilitate real-time checking and validation of the certificates. (Khandelwal et al., 2020; Kumutha & Jayalakshmi, 2022)
- **Real Time Baggage Tracking:** (Hardiman & Gallagher, 2023) state "[..] there were more than 684,000 lost and mishandled bags at major US airlines in the first quarter of 2022 alone." Mismanaged luggage not only inconveniences travellers but also generates duplicate tasks and supplementary expenses for operators. It is theorized that integrating RFID technology with a blockchain database accessible to baggage handlers and owners could reduce instances of mishandled luggage or streamline the process of returning lost items. (Hasan et al., 2019; Salah et al., 2020)
- **Air Ticketing:** Airlines increasingly favour digital QR-based tickets over paper ones for improved customer service and cost reduction. However, in situations like missed flights or sudden deboarding, passengers still face cumbersome paperwork. Blockchain technology offers a solution by securing ticket validity and accuracy, enabling fast refunds for cancelled tickets, streamlining ticket transfers between airline alliances, and promptly notifying passengers of flight cancellations, thus enhancing operational efficiency and customer satisfaction (Ahmad et al., 2021b; Sahoo & Pasayat, 2023).
- **Collaborative Airport Decision Making:** CADMs are teams, that focus on optimizing airport resources to ensure a seamless customer experience for passengers. With the continuously rising number of passengers, issues such as single points of failure for stakeholders are becoming more common. It is hypothesized that with multi-signature smart contracts decision processes can be streamlined leading to a more responsive entity. (Ahmad et al., 2021b)

A.2. Component Lifecycle

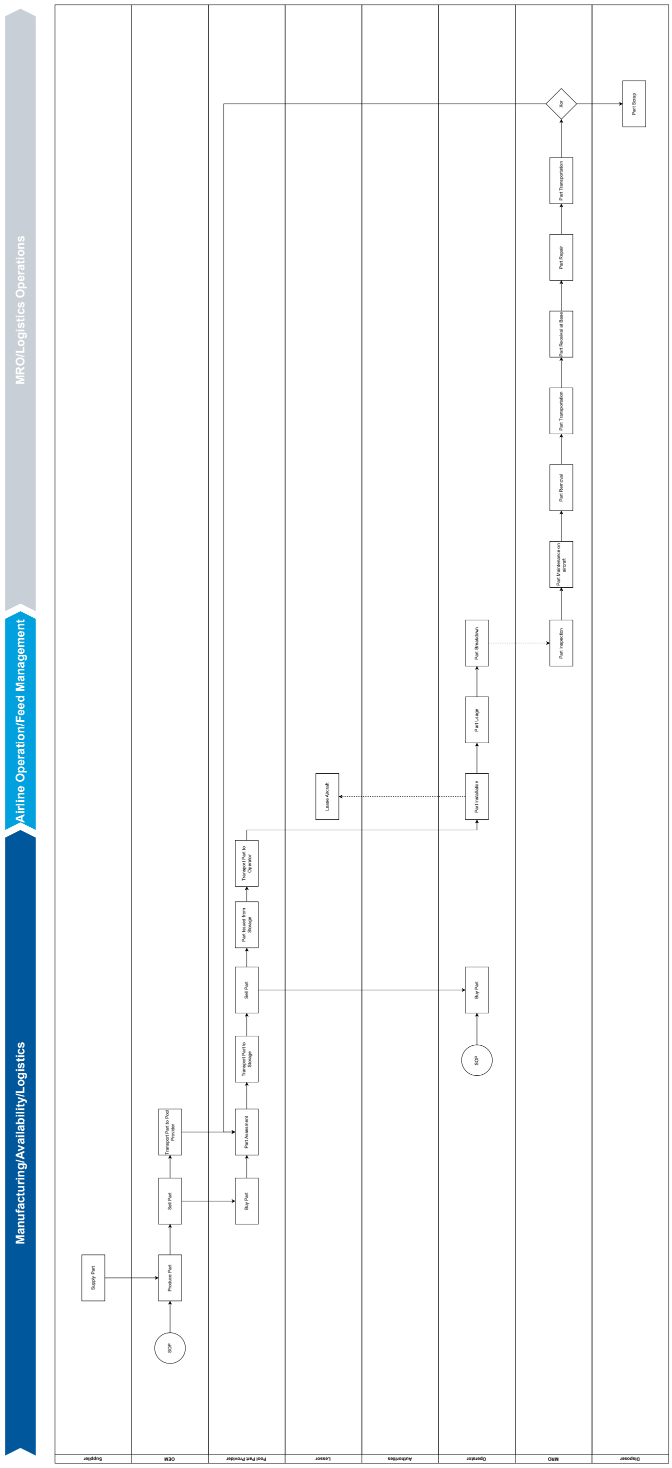

Figure A.1: High-level Lifecycle of Aircraft Component

B Appendix B - Interviews

B.1. Interview Protocol

Interview with Blockchain Experts in Aviation

Introduction of Interview

Hello!

I am Akal Devin Aras, a second year management of technology student at the Technical University of Delft. Currently I am pursuing my master thesis on Blockchain Governance Arrangements in aviation part tracking consortium. I am interested in understanding the values that stakeholder have during their participation in a blockchain part-tracking consortium from your perspective. With your answers, I hope to create governance arrangements which will be later evaluated by yourself. The goal of creating new governance arrangements is to ensure increased and long-term sustained participation from stakeholders.

Before we begin, I would like to ensure the information you provide is going to be treated anonymously and that all the collected data is going to be handled confidentially. You can always withdraw from the interview at any point.

Please share your perspective on the topics with me, as there are no right or wrong answers. Additionally, always feel free to interrupt or correct me.

Lastly, are you comfortable with me recording the audio? (Check the informed consent form).

Make sure that the informed consent form is signed!

Interview Starts

Dear Mr. Mrs. ……, thank you for joining the interview. Before we start our discussion I would like to read once more the definitions of a few key terms to ensure that we are completely aligned while using them. Additionally if you have any questions regarding these terms or you want to ask other clarifying questions please do not hesitate!

General main Questions

Now / Get to know:

- Could you maybe introduce yourself?
- What kind of project involvements do you OR did you have with blockchain data consortiums in aviation?
  - What role have you played within them?

Past questions for experienced people:

- You have mentioned project X, during the project were there any governance arrangements or processes that you did not totally agree with **and why**?
- You have mentioned project X, during the project were there any governance arrangements or processes that you completely agreed with **and why**?
- You have mentioned project X, during the project what governance arrangements did stakeholders debate the most about **and why**?
- What aspect of Blockchain technology makes you most uncomfortable during the implementation or usage **and why**?

Future:

- Say you are going into collaboration with aviation entities to share data on the lifecycle of spare parts, what boundary(s) being crossed would make you want to quit the consortium **and why**?
- Say you are going into collaboration with aviation entities to share data on the lifecycle of spare parts, what would make you to invite others to join the consortium **and why**?
- So you have mentioned values X,Y,Z, how do you think in processes or arrangements it should be made sure that they are addressed?

Figure B.1: Interview Protocol First Page

Conclusion:

- Finally is there anything you would still like to add to your answers or do you have any comments?

Guidance Examples

- Example 1: KLM → In 2018 AirFrance/KLM engineering and maintenance division has initiated a blockchain project with the aim of improving the aircraft maintenance process. However, the project soon arrived to an end because other parties were not keen on joining as AirFrance/KLM group was the central entity which created automatic competition and inequalities making it unfavoruable for other stakeholders to join → Value: Power Equality
- Example 2: TradeLens → Between 2018 and 2022 A.P. Moller Maersk one of the biggest shipping companies worldwide together with IBM have founded TradeLends to digitize the full Supply Chain of shipping containers as an open and neutral industry platform. However although a viable platform was developed the stakeholders could not agree on who is going to pay for what which led Maersk and IBM withdraw from the project. → Value: Financial Fairness
- Example 3: Australian Stock Exchange → The Australian Stock Exchange market has announced 7 years ago a plan to upgrade clearing and settlement of shares to a blockchain-based platform. However they have have abandoned the project this November citing concerns about the product's complexity and scalability, and difficulty finding experts to support it. → Value: Technical Usefullness

Figure B.2: Interview Protocol Second Page

Pre-Interview Guide

Dear participant,

Once more thank you very much for agreeing to participate in my master's thesis interview.

This document is intended to ensure that we have a shared understanding of key terms that will be used during the interviews. If you have any questions or disagreements about the definitions provided, please feel free to discuss them with me before the interview begins. Prior to the interview, I will review these definitions with you once again to ensure clarity so you do not need to worry about memorizing them.

Key Terms	Definition
Consortium Blockchain	Semi-decentralized type of blockchain where usually, more than one organization manages the system. The blockchain maintains limited to no accessibility for external parties while trying to remain publicly accessible to internal participants
Stakeholders	A person or an entity who is involved with an organization, society, etc. and therefore has responsibilities towards it and an interest in its success.
Stakeholder Values	Fundamental beliefs that guide behaviors and actions within a group or society.
Blockchain Governance Arrangements	The jointly made decision by stakeholders which aims to define the direction (purpose and long-term vision), control (management) and coordination (resources, activities and timelines) of a given blockchain project to which they jointly contribute
Blockchain Governance Process	The course of action during which a series of steps are taken by entities leading to the decision of a Governance arrangement

Figure B.3: Pre-Interview Guide

Delft University of Technology
HUMAN RESEARCH ETHICS
INFORMED CONSENT FORM
2024

You are being invited to participate in a research study titled Blockchain Governance to Facilitate the Collaboration between Members of a Digital Twin Aviation Consortium. This study is being done by Akal Devin Aras from the TU Delft.

The purpose of this research study is to construct governance arrangements which could help managers to make informed decisions during the lifecycle of a blockchain consortium and will take you approximately 30 minutes to complete. We will discuss the following topics: ‘ Stakeholder Values’ and, ‘Blockchain Consortium Governance’. The interview will be recorded and, the recording will be transcribed for analysis. Your input will be used in an aggregated form as part of the result section of the thesis. I want to make it clear that only your job description will be publicly disclosed upon the completion of the project when the MSc thesis becomes publicly available.

As with any online activity the risk of a breach is always possible. To the best of our ability your answers in this study will remain confidential. We will minimize any risks by relying on TUD infrastructure for data storage during the project, accessible only to the relevant project members (Akal Devin Aras, Jolien Ubacht, Marcela Tuler de Oliviera).

The personal data collected during the study will be preserved for up to 2 years after the completion of the project (estimated date: August 2026), after which it will be destroyed. The data may be reused for scientific publication, educational material and presentations on the topic of Governance of blockchain consortium. In all output, you will be fully anonymous. Should we want to use the data for any other purposes, we will reach out to you and request your permission.

Your participation in this study is entirely voluntary and you can withdraw at any time. You are free to omit any questions.

PLEASE TICK THE APPROPRIATE BOXES	**Yes**	**No**
I agree that my responses, views or other input can be quoted anonymously in research outputs	☐	☐

I have read and understood, and I agree to participate in the study and the processing of my personal data.

Signature

_________________________ _________________________ ________

Name of participant Signature Date

I, as researcher, have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting.

Akal Devin Aras A.D.Aras

Researcher name Signature Date

Study contact details for further information:

Akal Devin Aras, A.D.Aras@student.tudelft.nl

Jolien Ubacht, J.Ubacht@tudelft.nl

Figure B.4: Consent Form Interviews

B.2. Final Value Definitions for Survey Usage

B.2.1. Data Value Definitions

- **Accessibility Control:** The ability to determine who can see and utilize the data you upload to the chain.

- **Confidentiality:** Confidentiality refers to protecting any type of financial data and intellectual property that could be derived from data sharing.
  - **Financial Confidentiality:** The protection of all stakeholders' financial, and transactional information from it being uploaded to the chain or derived from uploaded data.
  - **IP Confidentiality:** The protection of all stakeholders' intellectual property or any data that could give a hint regarding their intellectual property from it being uploaded to the chain.
  - **Integrity:** Data integrity is the accuracy, completeness, and quality of data as it is maintained over time and across formats.

  - **Ownership:** Data ownership refers to both the possession of and responsibility for information.

B.2.2. Blockchain Value Definitions

- **Adaptability:** The ability to change in order to suit different conditions. In this project, adaptability means entails; when alliances change (stakeholders join or leave), the technology should seamlessly adapt to these changes.

- **Compatibility:** The value of integration with existing IT systems for a smooth data transfer and usage.

- **Ease of use & Understandability:** The degree of ease associated with the use and understandability of the system.

- **Security:** Concerns with how safe the system is from facing malicious attacks.

- **Sustainability:** The effect that the technology has on the environment to maintain the network.

- **Tangebility:** Capability of being demonstrated and logically proved to the stakeholders.

B.2.3. Stakeholder Value Definitions

- **Awarness:** Awarness is described by the understanding of the need and benefit of sharing data at the present time based on current inefficiencies. In our case, it is the understanding by stakeholders that data sharing is both needed from a security perspective as well as beneficial for all individual entities.

- **Benefit Equality:** Benefit equality implies that all stakeholders involved would receive equal benefits either in monetary terms or KPIs.
  - **Fair Value Distribution:** Fair value distribution entails that if any monetary or non-monetary value is generated by the totality of the stakeholders it should be distributed equally among them.
  - **Gaining Unequal Competitive Advantage:** The ability for stakeholders to use shared data against the original data sharer in such a manner that the original sharing stakeholder could not have used.

- **Compliance:** Compliance describes the act of obeying the predetermined laws or rules of the consortium.

- **Growth:** Growth describes the totality of new stakeholders joining the consortium.
  - **Network Effects:** Network effects describe ensuring more and more stakeholders join regardless of their location, size or position in the aircraft part lifecycle.
  - **Stakeholder Representation:** Stakeholder represantation describes ensuring stakeholder representation from various stages of the aircraft part lifecycle.
- **Legitimacy:** Legitimacy describes the involvement of authorities (EASA) in the data-sharing consortium and the consideration of relevant regulations, such as the GDPR.
  - **Involvement of Regulations:** The implementation of data rules and regulations (GDPR, CSDR) within the data sharing consortium.
  - **Involvement of Authorities:** The involvement of aviation regulators (EASA) within the consortium.

- **Neutrality:** Neutrality is described as not being in favor of a specific group of stakeholders. In the context of this project, it should be considered together with the principle of separation of powers (legislative, executive, and judicial) preventing the concentration of power and ensuring neutrality.
  - **Legislative Neutrality:** Legislative neutrality pertains to the impartial creation of laws governing data sharing among stakeholders.
  - **Executive Neutrality:** Executive neutrality pertains to the impartial execution of laws governing data sharing among stakeholders.
  - **Arbitrage Neutrality:** Arbitrage neutrality pertains to the impartial resolvement of disputes and disagreements among stakeholders.

- **Trust:** Trust is the belief in the reliability, truth, or ability of stakeholders.

C Appendix C - Survey

C.1. Survey Questions

Stakeholder Survey Final

Start of Block: Opening Statement

OPENING STATEMENT

Dear Sir/Madam, you are cordially invited to participate in a research study titled **“Establishing Governance Mechanisms for Long-term Blockchain Part-Tracking Consortium in Aviation”.**

According to the International Air Transport Association (IATA), tracking and tracing aircraft components throughout their lifecycle is crucial. However, this process is challenging and complicated due to several factors such as aircraft configuration, spare part management systems, supply chains and the nature of communication.

Joining a data sharing blockchain consortium in the aviation industry could help solve this issue due the technology’s features and exchange of data. The purpose of this research study is to understand the **values of stakeholders** influencing the joining of data sharing blockchain consortium and **provide recommendations** on the topic for **data sharing consortiums using blockchain technology.**

This survey is part of the master thesis of Akal Devin Aras from Delft University of Technology (TU Delft), The Netherlands, supervised by Dr. Ir. M. Tuler de Oliveira and Dr. J. Ubacht from TU Delft.

This survey will take you approximately **15-20 minutes** to complete. We hope you are willing to share your assessment, which is paramount to our study. The survey follows the **Best-Worst Method** and consists of **2 steps**.

1. First, you will be asked to choose (from a provided list) the most and the least important values per category (Blockchain, Stakeholder and Data). These values are described during the survey.

2. Second, you will be asked to **rank the remaining values** from the list, **compared to the most and least important value chosen in the first step.**

This allows the researcher to have a ranking of the stakeholder values which will allow him to retrieve **meaningful insights** on how to increase stakeholder participation in a blockchain data sharing aviation consortium.

As with any online activity the risk of a breach is always possible. To the best of our ability and knowledge your answers in this study will remain anonymous. We will minimize any risks by not

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Figure C.1: Stakeholder Survey Questions

asking any personal data such as name, address, email or nationality, and by presenting the data in aggregate form only, in Akal's Master Thesis report and any potential publications that might arise from it.

You are free to stop the survey at any time. However, **once submitted,** the answers are **cannot be deleted** as the survey is anonymous. If you are interested in receiving more information about this research, you can contact: A.D.Aras@student.tudelft.nl at any time.

By clicking **"Next"** to continue this online survey, **you agree to this opening statement.**

Thank you in advance for your participation.

Kind regards,

Akal Devin Aras

End of Block: Opening Statement

Start of Block: Knowledge Equalization

Figure C.1: Stakeholder Survey Questions

Establishing a Common Understanding

What is a data-sharing consortium in the aviation industry?

One of the initiatives of data sharing in the aviation industry, namely Independent Data Consortium for Aviation (IDCA) defines themself as: "A global consortium of leading aviation companies at all levels of the industry coming together to develop the foundation for allowing data to be shared in a non-competitive manner. This type of data sharing will allow the industry to achieve gains in sustainability, safety, compliance, value creation, cost reduction and innovation at a scale that no single organization could achieve on its own. " Up until now, different use cases have been studied:

- Parts tracking from birth to disposal
- Aircraft on Ground (AOG) servicing
- Lease ownership transfer
- Diagnosing technical problems common to all operators
- Preserving mandatory aircraft safety data even in areas experiencing conflict

This survey will have a specific emphasis on the parts tracking from birth to disposal use case. If you want to learn more about IDCA feel free to check out the link.

Why is Blockchain Technology one of the potential solutions?

This video is a short animation which introduces **Blockchain technology as a potential solution** to benefit the use case of parts tracking from birth to disposal. According to the International Air Transport Association (IATA), tracking and tracing aircraft components throughout their lifecycle is crucial. However, this process is challenging and complicated due to several factors such as aircraft configuration, spare part management systems and supply chains and the nature of communication.

If you are already familiar with the concept of blockchain technology, feel free to **continue without watching the video.**

What is the Best-Worst Method?

In this questionnaire, we will follow the **Best-Worst Method.** This is a **multi-criteria decision-making** method, that allows you to **rank values** that will be presented to you. A **value** is a condition that **influences** decision-makers **to join or not to join** a data-sharing consortium with their organization. The **values** have been divided into **three factors**: Blockchain, Stakeholder and Data.

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Figure C.1: Stakeholder Survey Questions

The Method:
In each category of values, you will:

- **Be presented** with a **list of values** for joining a data-sharing consortium for parts tracking from birth to disposal in the aviation supply chain found in the literature and expert interviews.
- **Choose** the most important value when considering joining a data-sharing consortium with your organization
- **Choose** the least important value when considering joining a data-sharing consortium with your organization
- **Indicate**, from **1-9** how much more you **prefer the most important value chosen** compared to the **other values.**

End of Block: Knowledge Equalization

Start of Block: Introduction

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Figure C.1: Stakeholder Survey Questions

Q1. Do you work in the aviation industry or are you familiar with it?

- ◯ Yes, I currently work in the aviation industry
- ◯ Yes, I am familiar with the industry even though I do not currently work in the aviation industry
- ◯ No, I am not familiar

Q2. Which role in the aircraft component supply chain does/did your organization play?

- ◯ Tier 1 Supplier
- ◯ Original Equipment Manufacturer
- ◯ Pool Provider
- ◯ Operator
- ◯ Lessor
- ◯ Maintenance Repair Overhaul
- ◯ Disposer - Recycler
- ◯ Regulators

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Figure C.1: Stakeholder Survey Questions

Q3. What is/was your main **job scope**?

- ○ R&D
- ○ Production/Manufacturing
- ○ Technology Implementation
- ○ Procurement
- ○ Project Management
- ○ Supply Chain / Logistics
- ○ Marketing
- ○ Other: ____

End of Block: Introduction

Start of Block: Layer 1

Q4. Suppose, as a decision-maker in your organization, you have the opportunity to join a blockchain data sharing consortium.

Of the following factors, which one is, in your opinion, the **MOST IMPORTANT** factor you would consider when deciding whether to join such a consortium or not?

- ○ BLOCKCHAIN platform that the consortium is going to use
- ○ STAKEHOLDERS that the consortium is going to encompass
- ○ DATA that the consortium is going to handle (Share/Receive/Store)

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Figure C.1: Stakeholder Survey Questions

Q5. Of the following factors, which one is, in your opinion, the **LEAST IMPORTANT** factor you would consider when deciding whether to join such a consortium or not?

○ BLOCKCHAIN platform that the consortium is going to use

○ STAKEHOLDERS that the consortium is going to encompass

○ DATA that the consortium is going to handle (Share/Receive/Store)

Page Break

You have now selected the most and least important factors for you. We will now ask you to indicate, from 1-9 how much more you prefer the chosen values compared to the other values. The rest of the questionnaire will be exactly this approach. You will be asked to select the most and least important values and afterwards indicate how much more/less you prefer them.

Page Break

Q6. You have selected "${B.Q1/ChoiceGroup/SelectedChoices}" as the **MOST IMPORTANT** factor. Please indicate **how much you prefer** "${B.Q1/ChoiceGroup/SelectedChoices}" over the other factors.

(E.g. I think that "${B.Q1/ChoiceGroup/SelectedChoices}" is **extremely more important** than the "${e://Field/__js_undecided1}" --> Put slide bar of "${e://Field/__js_undecided1}" to **9**.

E.g. I think that "${B.Q1/ChoiceGroup/SelectedChoices}" is **equally important** as the"${e://Field/__js_undecided1}" --> Put slide bar of "${e://Field/__js_undecided1}" to **1**.)

Scale measurement from 1 to 9 where:
1: Equally important & 9: Extremely more important

	1 2 3 4 5 6 7 8 9
${B.Q1/ChoiceDescription/1} ()	
${B.Q1/ChoiceDescription/2} ()	
${B.Q1/ChoiceDescription/3} ()	

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Figure C.1: Stakeholder Survey Questions

Q7. You have selected "${B.Q2/ChoiceGroup/SelectedChoices}" as the **LEAST IMPORTANT** factor. Please indicate how much you **prefer each of the other factors over** "${B.Q2/ChoiceGroup/SelectedChoices}".

(E.g. I think that "${e://Field/__js_undecided2}" is **extremely more important than** the "${B.Q2/ChoiceGroup/SelectedChoices}" --> Put slide bar of "${e://Field/__js_undecided2}" to **9**.

E.g. I think that "${e://Field/__js_undecided2}" is **equally important** as the "${B.Q2/ChoiceGroup/SelectedChoices}" --> Put slide bar of "${e://Field/__js_undecided2}" to **1**.)

Scale measurement from 1 to 9 where:
1: Equally important & 9: Extremely more important

	1 2 3 4 5 6 7 8 9
${B.Q2/ChoiceDescription/1} ()	
${B.Q2/ChoiceDescription/2} ()	
${B.Q2/ChoiceDescription/3} ()	

End of Block: Layer 1

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Figure C.1: Stakeholder Survey Questions

Start of Block: Data

Data Value Definitions:
Accessibility Control: *The ability to determine who can see and utilize the data you upload to the chain.*
Integrity: *Data integrity is the accuracy, completeness, and quality of data as it is maintained over time and across formats.*
Ownership: *Data ownership refers to both the possession of and responsibility for information.*
Confidentiality: *Confidentiality refers to protecting any type of financial data and intellectual property that could be derived from data sharing.*

Q8. Of the following **DATA VALUES**, which one is, in your opinion, the **MOST IMPORTANT** value you would consider when deciding whether to join such a consortium or not?

◯ Accessibility Control

◯ Integrity

◯ Ownership

◯ Confidentiality

Q9. Of the following **DATA VALUES**, which one is, in your opinion, the **LEAST IMPORTANT** value you would consider when deciding whether to join such a consortium or not?

◯ Accessibility Control

◯ Integrity

◯ Ownership

◯ Confidentiality

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Figure C.1: Stakeholder Survey Questions

Q10. You have selected "${C.Q1/ChoiceGroup/SelectedChoices}" as the **MOST IMPORTANT** data value.

Please indicate **how much you prefer** "${C.Q1/ChoiceGroup/SelectedChoices}" over the other data values.

Scale measurement from 1 to 9 where:
1: Equally important & 9: Extremely more important

	1	2	3	4	5	6	7	8	9
${C.Q1/ChoiceDescription/1} ()									
${C.Q1/ChoiceDescription/2} ()									
${C.Q1/ChoiceDescription/3} ()									
${C.Q1/ChoiceDescription/4} ()									

Q11. You have selected "${C.Q2/ChoiceGroup/SelectedChoices}" as the **LEAST IMPORTANT** data value.

Please indicate how much you **prefer each of the other values over** "${C.Q2/ChoiceGroup/SelectedChoices}".

Scale measurement from 1 to 9 where:
1: Equally important & 9: Extremely more important

	1	2	3	4	5	6	7	8	9
${C.Q2/ChoiceDescription/1} ()									
${C.Q2/ChoiceDescription/2} ()									
${C.Q2/ChoiceDescription/3} ()									
${C.Q2/ChoiceDescription/4} ()									

End of Block: Data

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Figure C.1: Stakeholder Survey Questions

Start of Block: Confidentiality

Confidentiality Value Definitions:
Financial Confidentiality: *The protection of all stakeholders financial, and transactional information from it being uploaded to the chain or derived from uploaded data.*
IP Confidentiality: *The protection of all stakeholders intellectual property or any data that could give a hint regarding their intellectual property from it being uploaded to the chain.*

Q12. Of the following **CONFIDENTIALITY VALUES**, which one is, in your opinion, the **MOST IMPORTANT** value you would consider when deciding whether to join such a consortium or not?

- ◯ Financial Confidentiality
- ◯ IP Confidentiality

Q13. Of the following **CONFIDENTIALITY VALUES**, which one is, in your opinion, the **LEAST IMPORTANT** value you would consider when deciding whether to join such a consortium or not?

- ◯ Financial Confidentiality
- ◯ IP Confidentiality

Q14. You have selected "${Q45/ChoiceGroup/SelectedChoices}" as the **MOST IMPORTANT** confidentiality value.

Please indicate how much you prefer "${Q45/ChoiceGroup/SelectedChoices}" over the other category of confidentiality value.

Scale measurement from 1 to 9 where:
1: Equally important & 9: Extremely more important

	1 2 3 4 5 6 7 8 9
${Q45/ChoiceDescription/1} ()	
${Q45/ChoiceDescription/2} ()	

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Figure C.1: Stakeholder Survey Questions

Q15. You have selected "${Q45/ChoiceGroup/UnselectedChoices}" as the **LEAST IMPORTANT** confidentiality value.

Please indicate how much you **prefer each of the other categories of values over** "${Q45/ChoiceGroup/UnselectedChoices}".

Scale measurement from 1 to 9 where:
1: Equally important & 9: Extremely more important

	1	2	3	4	5	6	7	8	9
${Q46/ChoiceDescription/1} ()									
${Q46/ChoiceDescription/2} ()									

End of Block: Confidentiality

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Figure C.1: Stakeholder Survey Questions

Start of Block: Stakeholder

Stakeholder Value Definitions:
Awarness: *Awarness is described by the understanding of the need and benefit of sharing data at the present time based on current inefficiencies. In our case, it is the understanding by stakeholders that data sharing is both needed from a security perspective as well as beneficial for all individual entities.*
Benefit Equality: *Benefit equality implies that all stakeholders involved would receive equal benefits either in monetary terms or KPIs.*
Compliance: *Compliance describes the act of obeying the predetermined laws or rules of the consortium.*
Legitimacy: *Legitimacy describes the involvement of authorities (EASA) in the data-sharing consortium and the consideration of relevant regulations, such as the GDPR.*
Neutrality: *Neutrality is described as not being in favor of a specific group of stakeholders. In the context of this project, it should be considered together with the principle of separation of powers (legislative, executive, and judicial) preventing the concentration of power and ensuring neutrality in decision making.*
Trust: *Trust is the belief in the reliability, truth, or ability of stakeholders.*
Growth: *Growth describes the totality of new stakeholders joining the consortium.*

Q16. Of the following **STAKEHOLDER VALUES**, which one is, in your opinion, the **MOST IMPORTANT** value you would consider when deciding whether to join such a consortium or not?

- ○ Awareness
- ○ Benefit Equality
- ○ Compliance
- ○ Legitimacy
- ○ Neutrality
- ○ Trust
- ○ Growth

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Figure C.1: Stakeholder Survey Questions

Q17. Of the following **STAKEHOLDER VALUES**, which one is, in your opinion, the **LEAST IMPORTANT** value you would consider when deciding whether to join such a consortium or not?

- ◯ Awareness
- ◯ Benefit Equality
- ◯ Compliance
- ◯ Legitimacy
- ◯ Neutrality
- ◯ Trust
- ◯ Growth

Q18. You have selected "${D.Q1/ChoiceGroup/SelectedChoices}" as the **MOST IMPORTANT** stakeholder value.

Please indicate how much you prefer "${D.Q1/ChoiceGroup/SelectedChoices}" over the other values.

Scale measurement from 1 to 9 where:
1: Equally important & 9: Extremely more important

	1 2 3 4 5 6 7 8 9
${D.Q1/ChoiceDescription/1} ()	
${D.Q1/ChoiceDescription/2} ()	
${D.Q1/ChoiceDescription/3} ()	
${D.Q1/ChoiceDescription/4} ()	
${D.Q1/ChoiceDescription/5} ()	
${D.Q1/ChoiceDescription/6} ()	
${D.Q1/ChoiceDescription/7} ()	

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Figure C.1: Stakeholder Survey Questions

Q19. You have selected "${D.Q2/ChoiceGroup/SelectedChoices}" as the **LEAST IMPORTANT** stakeholder value.

Please indicate how much you **prefer each of the other values over** "${D.Q2/ChoiceGroup/SelectedChoices}".

Scale measurement from 1 to 9 where:
1: Equally important & 9: Extremely more important

	1	2	3	4	5	6	7	8	9
${D.Q2/ChoiceDescription/1} ()									
${D.Q2/ChoiceDescription/2} ()									
${D.Q2/ChoiceDescription/3} ()									
${D.Q2/ChoiceDescription/4} ()									
${D.Q2/ChoiceDescription/5} ()									
${D.Q2/ChoiceDescription/6} ()									
${D.Q2/ChoiceDescription/7} ()									

End of Block: Stakeholder

Figure C.1: Stakeholder Survey Questions

Start of Block: Legitimacy

Legitimacy Value Definitions: ***Involvement of Regulations:*** *The enforcement of data rules and regulations (GDPR, CSDR)* within the data sharing consortium. ***Involvement of Authorities:*** *The involvement of aviation regulators (EASA) within the consortium.*

Q20. Of the following **legitimacy values**, which one is, in your opinion, the **MOST IMPORTANT** value you would consider when deciding whether to join such a consortium or not?

○ Involvement of Authorities

○ Involvement of Regulations

Q21. Of the following **legitimacy values**, which one is, in your opinion, the **LEAST IMPORTANT** value you would consider when deciding whether to join such a consortium or not?

○ Involvement of Authorities

○ Involvement of Regulations

Q22. You have selected "${Q25/ChoiceGroup/SelectedChoices}" as the **MOST IMPORTANT stakeholder legitimacy** value.

Please indicate how much you prefer "${Q25/ChoiceGroup/SelectedChoices}" over the other categories of data values.

Scale measurement from 1 to 9 where:
1: Equally important & 9: Extremely more important

	1 2 3 4 5 6 7 8 9
${Q25/ChoiceDescription/1} ()	
${Q25/ChoiceDescription/2} ()	

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Figure C.1: Stakeholder Survey Questions

Q23. You have selected "${Q29/ChoiceGroup/SelectedChoices}" as the **LEAST IMPORTANT** stakeholder legitimacy value.

Please indicate how much you **prefer each of the other categories of values over** "${Q29/ChoiceGroup/SelectedChoices}".

Scale measurement from 1 to 9 where:
1: Equally important & 9: Extremely more important

	1	2	3	4	5	6	7	8	9
${Q29/ChoiceDescription/1} ()									
${Q29/ChoiceDescription/2} ()									

End of Block: Legitimacy

Figure C.1: Stakeholder Survey Questions

Start of Block: Benefit Equality

Benefit Equality Value Definitions:

Fair Value Distribution: *Fair value distribution entails that if any* ***monetary*** *value is generated by the totality of the stakeholders it should be distributed equally among them.*
Gaining Competitive Advantage: *The ability for stakeholders to use shared data against the original data sharer in* ***non-monetary*** *terms as improving their operations.*

Q24. Of the following **benefit equality components**, which one is, in your opinion, the **MOST IMPORTANT** value you would consider when deciding whether to join such a consortium or not?

◯ Fair Value Distribution

◯ Gaining Competitive Advantage

Q25. Of the following **benefit equality components**, which one is, in your opinion, the **LEAST IMPORTANT** value you would consider when deciding whether to join such a consortium or not?

◯ Fair Value Distribution

◯ Gaining Competitive Advantage

Q26. You have selected "${Q61/ChoiceGroup/SelectedChoices}" as the **MOST IMPORTANT** benefit equality component of technology interaction value.

Please indicate how much you prefer "${Q61/ChoiceGroup/SelectedChoices}" over the other values.

Scale measurement from 1 to 9 where:
1: Equally important & 9: Extremely more important

	1 2 3 4 5 6 7 8 9
${Q61/ChoiceDescription/1} ()	
${Q61/ChoiceDescription/2} ()	

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Figure C.1: Stakeholder Survey Questions

Q27. You have selected "${Q62/ChoiceGroup/SelectedChoices}" as the **LEAST IMPORTANT** benefit equality component of technology interaction value.

Please indicate how much you **prefer each of the other values over** "${Q62/ChoiceGroup/SelectedChoices}".

Scale measurement from 1 to 9 where:
1: Equally important & 9: Extremely more important

	1	2	3	4	5	6	7	8	9
${Q62/ChoiceDescription/1} ()									
${Q62/ChoiceDescription/2} ()									

End of Block: Benefit Equality

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Figure C.1: Stakeholder Survey Questions

Start of Block: Neutrality

Neutrality Value Definitions:
Legislative Neutrality: *Legislative neutrality pertains to the impartial creation of laws governing data sharing among stakeholders.*
Executive Neutrality: *Executive neutrality pertains to the impartial execution of laws governing data sharing among stakeholders.*
Arbitrage Neutrality: *Arbitrage neutrality pertains to the impartial resolvement of disputes, disagreements among stakeholders.*

Q28. Of the following **neutrality components**, which one is, in your opinion, the **MOST IMPORTANT** value you would consider when deciding whether to join such a consortium or not?

○ Legislative Neutrality

○ Executive Neutrality

○ Arbitrage Neutrality

Q29. Of the following **neutrality components**, which one is, in your opinion, the **LEAST IMPORTANT** value you would consider when deciding whether to join such a consortium or not?

○ Legislative Neutrality

○ Executive Neutrality

○ Arbitrage Neutrality

Q30. You have selected "${Q68/ChoiceGroup/SelectedChoices}" as the **MOST IMPORTANT** neutrality value.

Please indicate how much you prefer "${Q68/ChoiceGroup/SelectedChoices}" over the other neutrality values.

Scale measurement from 1 to 9 where:
1: Equally important & 9: Extremely more important

1 2 3 4 5 6 7 8 9

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Figure C.1: Stakeholder Survey Questions

${Q68/ChoiceDescription/1} ()	
${Q68/ChoiceDescription/2} ()	
${Q68/ChoiceDescription/3} ()	

Q31. You have selected "${Q69/ChoiceGroup/SelectedChoices}" as the **LEAST IMPORTANT** neutrality value.

Please indicate how much you **prefer each of the other values over** "${Q69/ChoiceGroup/SelectedChoices}".

Scale measurement from 1 to 9 where:
1: Equally important & 9: Extremely more important

	1 2 3 4 5 6 7 8 9
${Q69/ChoiceDescription/1} ()	
${Q69/ChoiceDescription/2} ()	
${Q69/ChoiceDescription/3} ()	

End of Block: Neutrality

Figure C.1: Stakeholder Survey Questions

Start of Block: Growth

Growth Value Definitions:
Network Effects: *Network effects describe ensuring more and more stakeholders join regardless of their location, size or position in the aircraft part lifecycle.*
Stakeholder Representation: *Stakeholder represantation describes ensuring stakeholder representation from various stages of the aircraft part lifecycle.*

Q32. Of the following **growth values**, which one is, in your opinion, the **MOST IMPORTANT** value you would consider when deciding whether to join such a consortium or not?

○ Network Effects

○ Stakeholder Representation

Q33. Of the following **growth values**, which one is, in your opinion, the **LEAST IMPORTANT** value you would consider when deciding whether to join such a consortium or not?

○ Network Effects

○ Stakeholder Representation

Q34. You have selected "${Q84/ChoiceGroup/SelectedChoices}" as the **MOST IMPORTANT** growth value.

Please indicate how much you prefer "${Q84/ChoiceGroup/SelectedChoices}" over the other categories of values.

Scale measurement from 1 to 9 where:
1: Equally important & 9: Extremely more important

	1 2 3 4 5 6 7 8 9
${Q84/ChoiceDescription/1} ()	
${Q84/ChoiceDescription/2} ()	

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Figure C.1: Stakeholder Survey Questions

Q35. You have selected "${Q85/ChoiceGroup/SelectedChoices}" as the **LEAST IMPORTANT** growth value.

Please indicate how much you **prefer each of the other values over** "${Q85/ChoiceGroup/SelectedChoices}".

Scale measurement from 1 to 9 where:
1: Equally important & 9: Extremely more important

	1	2	3	4	5	6	7	8	9
${Q85/ChoiceDescription/1} ()									
${Q85/ChoiceDescription/2} ()									

End of Block: Growth

Figure C.1: Stakeholder Survey Questions

Start of Block:Blockchain

Blockchain Value Definitions:
Security: *Concerns with how safe the system is from facing malicious attacks.*
Tangebility: *Capability of being demonstrated and logically proved to the stakeholders.*
Ease of use & Understandability: *The degree of ease associated with the use and understandability of the system.*
Sustainability: *The effect that the technology has on the environment to maintain the network.*
Compatibility: *The value of integration with existing IT systems for a smooth data transfer and usage.*
Adaptability: *The ability to change in order to suit different conditions. In this project, adaptability means entails; when alliances change (stakeholders join or leave), the technology should seamlessly adapt to these changes.*

Q36. Of the following **BLOCKCHAIN VALUES**, which one is, in your opinion, the **MOST IMPORTANT** value you would consider when deciding whether to join such a consortium or not?

- ○ Security
- ○ Tangebility
- ○ Ease of use & understandability
- ○ Sustainability
- ○ Compatibility
- ○ Adaptability

Q37. Of the following **BLOCKCHAIN VALUES**, which one is, in your opinion, the **LEAST IMPORTANT** value you would consider when deciding whether to join such a consortium or not?

- ○ Security
- ○ Tangebility
- ○ Ease of use & understandability
- ○ Sustainability
- ○ Compatibility
- ○ Adaptability

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Figure C.1: Stakeholder Survey Questions

Q38. You have selected "${E.Q1/ChoiceGroup/SelectedChoices}" as the **MOST IMPORTANT** blockchain value.

Please indicate how much you prefer "${E.Q1/ChoiceGroup/SelectedChoices}" over the other values.

Scale measurement from 1 to 9 where:
1: Equally important & 9: Extremely more important

	1	2	3	4	5	6	7	8	9
${E.Q1/ChoiceDescription/1} ()									
${E.Q1/ChoiceDescription/2} ()									
${E.Q1/ChoiceDescription/3} ()									
${E.Q1/ChoiceDescription/4} ()									
${E.Q1/ChoiceDescription/5} ()									
${E.Q1/ChoiceDescription/6} ()									

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Figure C.1: Stakeholder Survey Questions

Q39. You have selected "${E.Q2/ChoiceGroup/SelectedChoices}" as the **LEAST IMPORTANT** blockchain value.

Please indicate how much you **prefer each of the other values over** "${E.Q2/ChoiceGroup/SelectedChoices}".

Scale measurement from 1 to 9 where:
1: Equally important & 9: Extremely more important

	1	2	3	4	5	6	7	8	9
${E.Q2/ChoiceDescription/1} ()									
${E.Q2/ChoiceDescription/2} ()									
${E.Q2/ChoiceDescription/3} ()									
${E.Q2/ChoiceDescription/4} ()									
${E.Q2/ChoiceDescription/5} ()									
${E.Q2/ChoiceDescription/6} ()									

End of Block: Blockchain

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Figure C.1: Stakeholder Survey Questions

C.2. Questionaire Coding

C.2.1. $q://QID3/ChoiceGroup/SelectedChoices

A part of Qualtrics' "Piped Text" feature is the $q://QID3/ChoiceGroup/SelectedChoices function. This feature makes it easier to enter data into the survey later on by enabling the survey to pull data from several sources, including earlier questions. Enabling "variable naming" in the survey questions is crucial for obtaining data from them. This function is used in questions 6,7,10,11,14,15,18,19,22,23,26,27,29,31,34,35,38,39.

C.2.2. $e://Field/undecided1

Another part of Qualtrics' Piped Text tool is the $e://Field/Undecided1 function. The establishment of an "Embedded Data" element with the name "Undecided1" within the survey flow is a prerequisite for using this function. Embedded data consists of a field (Undecided1) that represents the variable name and a value allocated to the field. Inspired by Lanzini (2020) and Lopes Vieira (2022) research, a custom JavaScript (JS) script was created to set the value of one of the uncertain alternatives to the variable "Undecided1". The code can be found in **Appendix C** this function was used in questions 6,7,10,11,14,15,18,19,22,23,26,27,29,31,34,35,38,39. However later it was decided that there were too many examples and for the sake of simplicity they were only kept at questions 6,7.

C.2.3. $q://QID3/ChoiceDescription/1

The Qualtrics' Carry Forward Logic feature results in the Piped Text functionality. This allows the survey editor to transfer responses from one question to another seamlessly. In this particular case, the editor utilized this feature to carry forward the respondents' selections of the most and least significant values. Subsequently, the editor employed Display Logic, another integrated Qualtrics feature, to hide these selected alternatives in subsequent questions. This ensured that respondents could only rank the values they had previously chosen in order of importance, thereby removing the earlier options from the list of possible answers to these questions. This function is used in questions 6,7,10,11,14,15,18,19,22,23,26,27,29,31,34,35,38,39.

C.3. Individual Survey Answers

Context	A-B	A-W	Value	A-B	A-W	Sub-value	A-B	A-W
Data	1	9	Integrity	1	9			
			Access Control	9	1			
			Confidentiality	1	6	IP Confidentiality	1	1
						Financial Confidentiality	1	1
			Ownership	1	6			
Blockchain	6	4	Security	1	9			
			Tangebility	1	9			
			Ease of use & Understandability	5	4			
			Sustainability	5	6			
			Compatibility	3	9			
			Adaptability	9	1			
Stakeholder	9	1	Benefit Equality	3	6	Fair Value Distribution	1	1
						Gaining Competitive Advantage	1	1
			Compliance	1	7			
			Awarness	6	2			
			Legitimacy	1	9	Involvement of Authorities	1	1
						Involvement of Regulations	1	1
			Neutrality	1	9	Legislative Neutrality	1	3
						Executive Neutrality	1	5
						Arbitrage Neutrality	4	1
			Trust	2	8			
			Growth	8	1	Network Effects	1	1
						Stakeholder Representation	1	1

Figure C.2: Disposer 1 Survey Answer

Context	A-B	A-W	Value	A-B	A-W	Sub-value	A-B	A-W
Data	7	5	Integrity	1	9			
			Access Control	6	5			
			Confidentiality	6	5	IP Confidentiality	6	1
						Financial Confidentiality	1	6
			Ownership	8	1			
Blockchain	8	1	Security	4	5			
			Tangebility	6	1			
			Ease of use & Understandability	6	1			
			Sustainability	1	8			
			Compatibility	2	5			
			Adaptability	2	4			
Stakeholder	1	7	Benefit Equality	3	6	Fair Value Distribution	1	1
						Gaining Competitive Advantage	1	1
			Compliance	2	7			
			Awarness	9	1			
			Legitimacy	1	7	Involvement of Authorities	1	1
						Involvement of Regulations	1	1
			Neutrality	1	7	Legislative Neutrality	1	3
						Executive Neutrality	3	1
						Arbitrage Neutrality	2	2
			Trust	1	9			
			Growth	6	3	Network Effects	1	4
						Stakeholder Representation	6	1

Figure C.3: Lessor 1 Survey Answer

Context	A-B	A-W	Value	A-B	A-W	Sub-value	A-B	A-W
Data	6	6	Integrity	1	8			
			Access Control	7	1			
			Confidentiality	6	6	IP Confidentiality	5	1
						Financial Confidentiality	1	5
			Ownership	6	6			
Blockchain	9	1	Security	5	7			
			Tangebility	6	7			
			Ease of use & Understandability	7	1			
			Sustainability	5	5			
			Compatibility	1	7			
			Adaptability	6	7			
Stakeholder	1	8	Benefit Equality	6	5	Fair Value Distribution	1	2
						Gaining Competitive Advantage	9	1
			Compliance	6	6			
			Awarness	7	1			
			Legitimacy	6	6	Involvement of Authorities	1	3
						Involvement of Regulations	7	1
			Neutrality	1	8	Legislative Neutrality	1	5
						Executive Neutrality	5	5
						Arbitrage Neutrality	5	1
			Trust	5	7			
			Growth	7	5	Network Effects	7	1
						Stakeholder Representation	1	4

Figure C.4: MRO 1 Survey Answer

Context	A-B	A-W	Value	A-B	A-W	Sub-value	A-B	A-W
Data	1	9	Integrity	8	2			
			Access Control	1	9			
			Confidentiality	9	1	IP Confidentiality	5	1
						Financial Confidentiality	1	5
			Ownership	5	6			
Blockchain	9	1	Security	9	1			
			Tangebility	1	9			
			Ease of use & Understandability	7	4			
			Sustainability	2	8			
			Compatibility	5	5			
			Adaptability	1	9			
Stakeholder	5	6	Benefit Equality	6	3	Fair Value Distribution	1	9
						Gaining Competitive Advantage	8	1
			Compliance	3	3			
			Awarness	6	3			
			Legitimacy	1	9	Involvement of Authorities	3	1
						Involvement of Regulations	1	5
			Neutrality	1	9	Legislative Neutrality	7	3
						Executive Neutrality	1	9
						Arbitrage Neutrality	9	1
			Trust	3	6			
			Growth	9	1	Network Effects	1	4
						Stakeholder Representation	6	1

Figure C.5: MRO 2 Survey Answer

Context	A-B	A-W	Value	A-B	A-W	Sub-value	A-B	A-W
Data	7	5	Integrity	4	5			
			Access Control	1	9			
			Confidentiality	4	7	IP Confidentiality	4	1
						Financial Confidentiality	1	8
			Ownership	7	1			
Blockchain	8	1	Security	1	7			
			Tangebility	2	3			
			Ease of use & Understandability	4	3			
			Sustainability	4	1			
			Compatibility	3	4			
			Adaptability	2	6			
Stakeholder	1	9	Benefit Equality	5	7	Fair Value Distribution	2	1
						Gaining Competitive Advantage	1	4
			Compliance	5	8			
			Awarness	6	7			
			Legitimacy	6	6	Involvement of Authorities	1	2
						Involvement of Regulations	1	5
			Neutrality	7	6	Legislative Neutrality	5	1
						Executive Neutrality	1	5
						Arbitrage Neutrality	3	4
			Trust	1	9			
			Growth	8	1	Network Effects	1	2
						Stakeholder Representation	6	1

Figure C.6: MRO 3 Survey Answer

Context	A-B	A-W	Value	A-B	A-W	Sub-value	A-B	A-W
Data	1	9	Integrity	7	7			
			Access Control	9	1			
			Confidentiality	1	9	IP Confidentiality	1	9
						Financial Confidentiality	7	1
			Ownership	8	8			
Blockchain	9	1	Security	8	1			
			Tangebility	1	9			
			Ease of use & Understandability	8	7			
			Sustainability	9	1			
			Compatibility	9	1			
			Adaptability	6	6			
Stakeholder	8	8	Benefit Equality	2	2	Fair Value Distribution	7	1
						Gaining Competitive Advantage	1	6
			Compliance	8	9			
			Awarness	6	9			
			Legitimacy	7	8	Involvement of Authorities	6	1
						Involvement of Regulations	1	6
			Neutrality	5	4	Legislative Neutrality	1	6
						Executive Neutrality	9	1
						Arbitrage Neutrality	7	5
			Trust	1	9			
			Growth	9	1	Network Effects	5	1
						Stakeholder Representation	1	4

Figure C.7: Operator Survey Answer

Context	A-B	A-W	Value	A-B	A-W	Sub-value	A-B	A-W
Data	1	9	Integrity	7	1			
			Access Control	1	6			
			Confidentiality	5	5	IP Confidentiality	1	4
						Financial Confidentiality	2	1
			Ownership	1	7			
Blockchain	8	1	Security	2	6			
			Tangebility	7	1			
			Ease of use & Understandability	1	7			
			Sustainability	3	4			
			Compatibility	5	3			
			Adaptability	2	5			
Stakeholder	5	5	Benefit Equality	1	9	Fair Value Distribution	2	1
						Gaining Competitive Advantage	1	4
			Compliance	4	4			
			Awarness	5	4			
			Legitimacy	4	5	Involvement of Authorities	1	1
						Involvement of Regulations	1	1
			Neutrality	7	1	Legislative Neutrality	6	3
						Executive Neutrality	1	7
						Arbitrage Neutrality	4	1
			Trust	2	7			
			Growth	2	7	Network Effects	1	2
						Stakeholder Representation	6	1

Figure C.8: Operator 2 Survey Answer

Context	A-B	A-W	Value	A-B	A-W	Sub-value	A-B	A-W
Data	1	8	Integrity	1	2			
			Access Control	1	3			
			Confidentiality	2	1	IP Confidentiality	1	1
						Financial Confidentiality	1	1
			Ownership	1	2			
Blockchain	7	1	Security	1	6			
			Tangebility	1	7			
			Ease of use & Understandability	9	1			
			Sustainability	4	5			
			Compatibility	6	5			
			Adaptability	1	7			
Stakeholder	3	4	Benefit Equality	3	5	Fair Value Distribution	1	1
						Gaining Competitive Advantage	1	1
			Compliance	1	8			
			Awarness	8	1			
			Legitimacy	2	8	Involvement of Authorities	1	2
						Involvement of Regulations	2	1
			Neutrality	1	9	Legislative Neutrality	1	3
						Executive Neutrality	2	2
						Arbitrage Neutrality	4	1
			Trust	1	9			
			Growth	7	5	Network Effects	5	1
						Stakeholder Representation	1	4

Figure C.9: Pool Provider Survey Answer

Context	A-B	A-W	Value	A-B	A-W	Sub-value	A-B	A-W
Data	9	1	Integrity	1	9			
			Access Control	8	7			
			Confidentiality	6	5	IP Confidentiality	8	1
						Financial Confidentiality	1	9
			Ownership	9	1			
Blockchain	7	7	Security	1	9			
			Tangebility	6	6			
			Ease of use & Understandability	9	1			
			Sustainability	4	4			
			Compatibility	5	5			
			Adaptability	7	7			
Stakeholder	1	9	Benefit Equality	9	1	Fair Value Distribution	4	1
						Gaining Competitive Advantage	1	9
			Compliance	8	8			
			Awarness	6	5			
			Legitimacy	7	7	Involvement of Authorities	7	1
						Involvement of Regulations	1	9
			Neutrality	6	6	Legislative Neutrality	1	9
						Executive Neutrality	9	1
						Arbitrage Neutrality	7	7
			Trust	1	9			
			Growth	4	3	Network Effects	1	9
						Stakeholder Representation	5	1

Figure C.10: Regulator Survey Answer

Context	A-B	A-W	Value	A-B	A-W	Sub-value	A-B	A-W
Data	1	7	Integrity	7	1			
			Access Control	1	9			
			Confidentiality	3	7	IP Confidentiality	1	6
						Financial Confidentiality	7	1
			Ownership	1	9			
Blockchain	5	4	Security	3	7			
			Tangebility	4	6			
			Ease of use & Understandability	5	1			
			Sustainability	3	7			
			Compatibility	1	9			
			Adaptability	3	7			
Stakeholder	8	1	Benefit Equality	4	6	Fair Value Distribution	1	1
						Gaining Competitive Advantage	1	1
			Compliance	2	7			
			Awarness	9	1			
			Legitimacy	2	7	Involvement of Authorities	1	1
						Involvement of Regulations	1	1
			Neutrality	3	7	Legislative Neutrality	2	3
						Executive Neutrality	1	4
						Arbitrage Neutrality	4	1
			Trust	1	9			
			Growth	8	3	Network Effects	1	1
						Stakeholder Representation	1	1

Figure C.11: Tier 1 Supplier Survey Answer

Context	A-B	A-W	Value	A-B	A-W	Sub-value	A-B	A-W
Data	3	6	Integrity	1	9			
			Access Control	4	7			
			Confidentiality	3	6	IP Confidentiality	7	1
						Financial Confidentiality	1	5
			Ownership	5	1			
Blockchain	7	1	Security	1	9			
			Tangebility	9	1			
			Ease of use & Understandability	7	3			
			Sustainability	5	3			
			Compatibility	8	4			
			Adaptability	6	6			
Stakeholder	1	7	Benefit Equality	4	4	Fair Value Distribution	1	3
						Gaining Competitive Advantage	6	1
			Compliance	6	5			
			Awarness	5	3			
			Legitimacy	3	6	Involvement of Authorities	1	4
						Involvement of Regulations	6	1
			Neutrality	2	5	Legislative Neutrality	3	5
						Executive Neutrality	1	6
						Arbitrage Neutrality	4	1
			Trust	1	9			
			Growth	7	1	Network Effects	2	1
						Stakeholder Representation	1	2

Figure C.12: Tier 1 Supplier 2 Survey Answer

Context	A-B	A-W	Value	A-B	A-W	Sub-value	A-B	A-W
Data	1	9	Integrity	9	1			
			Access Control	1	9			
			Confidentiality	2	7	IP Confidentiality	1	1
						Financial Confidentiality	1	1
			Ownership	4	4			
Blockchain	5	7	Security	2	8			
			Tangebility	1	9			
			Ease of use & Understandability	4	3			
			Sustainability	6	1			
			Compatibility	2	8			
			Adaptability	3	8			
Stakeholder	9	1	Benefit Equality	5	3	Fair Value Distribution	1	1
						Gaining Competitive Advantage	1	1
			Compliance	2	8			
			Awarness	9	1			
			Legitimacy	2	8	Involvement of Authorities	1	1
						Involvement of Regulations	1	1
			Neutrality	1	9	Legislative Neutrality	1	5
						Executive Neutrality	1	5
						Arbitrage Neutrality	5	1
			Trust	1	9			
			Growth	7	3	Network Effects	1	1
						Stakeholder Representation	1	1

Figure C.13: OEM Survey Answer

C.4. Confidence Intervals

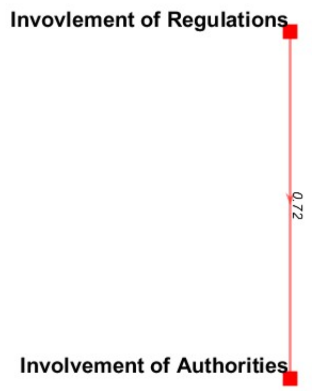

Figure C.14: Visualization of the credal ranking for Layer 3 - Legitimacy

Figure C.15: Visualization of the credal ranking for Layer 3 - Benefit Equality

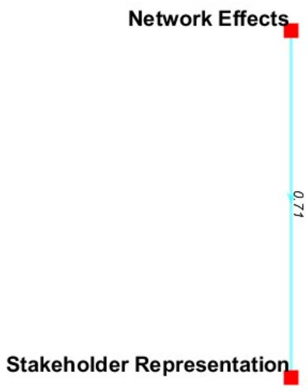

Figure C.16: Visualization of the credal ranking for Layer 3 - Growth

D Appendix D - Literature Review

D.1. Framework Papers

Table D.1: Final List of Papers for Value Identification

Title of Relevant Sources	Citation
Adoption of blockchain in Supply Chain: An analysis of influencing factors	Ghode et al. (2020)
Unblocking the chain – findings from an executive workshop on Blockchain in the supply chain	van Hoek (2019)
Evaluating the factors that influence blockchain adoption in the freight logistics industry	Orji et al. (2020)
Critical Success Factors of a Drug Traceability System for Creating Value in a Pharmaceutical Supply Chain (PSC)	Silva and Mattos (2019)
Blockchain technology and the sustainable supply chain: Theoretically exploring adoption barriers	Kouhizadeh et al. (2021a)
Blockchain technology and its relationships to sustainable supply chain management	Saberi et al. (2018)
An exploration of the role of blockchain in the sustainability and effectiveness of the Pharmaceutical Supply Chain	Alharthi et al. (2020)
Time to seize the digital evolution: Adoption of blockchain in operations and supply chain management among Malaysian smes	Wong et al. (2020)
Blockchain for aviation industry: Applications and used cases	J. Yadav et al. (2022)
Blockchain technology adoption barriers in the Indian agricultural supply chain: An integrated approach	Yadav et al. (2020)
Understanding blockchain technology for future supply chains: A Systematic Literature Review and Research Agenda	Wang et al. (2019)
Blockchain technology adoption, architecture, and sustainable agri-food supply chains	Saurabh and Dey (2021)
An Empirical Study of Factors Influencing E-Commerce Adoption/Non-Adoption in Slovakian SMEs	Walker et al. (2016)
Information and Communication Technology Adoption and Its Influencing Factors: A Study of Indian SMEs	Anjum (2019)
A perception-based model for EDI adoption in small businesses using a technology–organization–environment framework	Kuan and Chau (2001)
A model of adoption determinants of ERP within T-O-E framework	Awa and Ojiabo (2016)
An Exploratory Research on Blockchain in Aviation: The Case of Maintenance, Repair and Overhaul (MRO) Organizations	Efthymiou et al. (2022)

D.2. Governance Paper Analysis

Table D.2: An overview of past research on Blockchain Governance Definitions and Mechanisms 1

Paper	Blockchain Type			Blockchain Governance Definition	Blockchain Governance Mechanism	Blockchain Governance Level
	Public	Private	Consortium			
Framework for governance tailoring: case study for a blockchain-based supply chain application Ávila et al. (2022)		X		-	Decision process Accountability and verifiability Privacy and security Trust Incentive Effectiveness	-
Taxonomy of Blockchain Technologies: Principles of Identification and Classification Tasca and Tessone (2018)	X	X	X	-	-	Technical Rules Regulatory Rules
Multiple-Case Analysis on Governance Mechanism of Multi-Sided Platforms Hein et al. (2016)	X	X		-	Decision Rights Ownership Status Accessability Control Trust Perceived Risk Pricing External Relationship	-
A Cross-Sectional Overview of Cryptoasset Governance and Implications for Investors Carter (2017)	X			-	Consensus Mechanism Launch Style of Project Number of Coins Generated Support Funding Foundation Open Source	-
The Internal and External Governance of Blockchain-based Organizations: Evidence from Cryptocurrencies Hsieh et al. (2017)	X			"Blockchain governance is about determining who has authority how these actors are endowed in what form and at which level."	Control Voting Funding External Stakeholders	Blockchain Level Protocol Level Organizational Level
A Taxonomy for the Formation of Enterprise Blockchain Consortia Bons et al. (2023)			X	"Blockchain governance encompasses technical and social means to make decisions [...] related to [...] business, technological, legal, and regulatory aspects of a blockchain system during its whole lifecycle"	-	Administration Organizational Economical Technical Legal
The Digital Product Passport: Enabling Interoperable Information Flows Through Blockchain Consortia for Sustainability Greiner et al. (2024)		X	X	-	Decision Making Monitoring Sanctions Conflict Resolution Recognition Embedded Institutions Responsabilities Changes	-
Blockchain Governance: A Dynamic View Laatikainen et al. (2021)	X	X	X	Blockchain governance encompasses technical and social means to make decisions on the different levels related to actors, roles, rights, incentives, responsibilities, rules, and the business, technological, legal, and regulatory aspects of a blockchain system during its whole lifecycle.	Actors Roles Rights Rules and Responsibilities Incentives Technological Aspects Business Aspects Legal and Regulatory Aspects	Group Community Individual Organizational Inter-organizational National International

Table D.3: An overview of past research on Blockchain Governance Definitions and Mechanisms 2

Paper	Blockchain Type			Blockchain Governance Definition	Blockchain Governance Mechanism	Blockchain Governance Level
	Public	Private	Consortium			
Defining Blockchain Governance: A Framework for Analysis and Comparison Pelt et al. (2020)	X			"The means of achieving the direction, control, and coordination of stakeholders within the context of a given blockchain project to which they jointly contribute."	Formation and Context Roles Incentives Membership Communication Decision making Accountability	Off-chain Community Off-chain Development On-chain Protocol
Defining blockchain governance principles: A comprehensive framework Liu et al. (2022)	X	X		"Structures and processes which ensure that the development and use of blockchain are compliant with legal regulations and ethical responsibilities."	Decentralisation level Incentive Decision rights Accountability Stakeholder Ecosystem Lifecycle Legal compliance Ethical responsibility	-
Examining Gentle Rivalry: Decision-Making in Blockchain Systems Ziolkowski et al. (2019)	X	X		"The placement and enactment of decisionrights."	Decision Rights: Demand Management Data Authenticity System Architecture Membership Ownership Dispute Transaction Reversal	-
An Overview Of Governance In Blockchains Carter (2018)	X			"The way in which public blockchain communities and key stakeholders arrive at collective action, specifically with respect to protocol change."	-	On-Chain Off-Chain
Governance in the Blockchain Economy: A Framework and Research Agenda Beck et al. (2018)	X	X		"Combination between the extent of incentive alignment, the degree of centralization in decision rights, and the level to which accountability is either technically or institutionally enacted."	Decision rights Accountability, Incentives, Degree of Centralization	-
The invisible politics of Bitcoin: governance crisis of a decentralised infrastructure De Filippi and Loveluck (2016)	X			-	Community borders Incentives Status of contributors Conflict resolution	Infrastructure Level Community Level
Multistakeholder as Governance Groups: Observations from Case Studies Gasser et al. (2015)	X			-	Purpose and Motivations Architectural Composition Operation Outcomes	-
An Explorative Dive into Decision Rights and Governance of Blockchain: A Literature Review and Empirical Study Leewis et al. (2021)	X	X		"The means of achieving the direction, control, and coordination of stakeholders within the context of a given blockchain project to which they jointly contribute"	Decision Rights Decision Making Trust Participation rights Authorization Change management Incentives	-
The Dynamics of Governing Enterprise Blockchain Ecosystems van Haaren-van Duijn et al. (2022)			X	-	Access Rights Decision Rights Incentives Accountability Conflict Resolution	-
Governance and control in distributed ledgers: Understanding the challenges facing blockchain technology in financial services Zachariadis et al. (2019)	X	X		"Who makes what decisions about a platform"	Decision Rights Control Mechanisms Incentives	-
Blockchain Technology and Corporate Governance Akgiray (2018)	X			"Who makes the rules and who enforces them. It is about not only who controls the blockchain but also resolution mechanisms in case of technological, contractual default and crime."	Decision Making Resolution Mechanism Contractual Default Crime	-

E Appendix E - MATLAB Coding

E.1. MATLAB Code

E.1.1. Bayesian BWM

```
% A_B: a matrix containing best-to-others vectors from all decision-makers.
% A_W: a matrix containing other-to-worst vectors from all decision-makers.
%------------------------------------------------------------------------
% Copyright @ Majid Mohammadi,2019
% m.mohammadi@tudelft.nl
%------------------------------------------------------------------------


function [w_final,wall] = BayesianBWM(A_B,A_W)


k = size(A_B,1);
c = size(A_B,2);
wStar_prior = (1/10000000) * ones(size(A_W,2),1);
w = 1/k * ones(k,c);

% Save prior constants in a structure for later use with matjags
dataList = struct('AW',A_W,'AB',A_B,'wStarPrior',wStar_prior,'n',sum(A_B'),'m',sum(A_W'),'k',k,'c',c);

%% Specify MCMC properties
numSavedSteps = 300000;
nChains = 3;
thinSteps = 1;
burnInSteps = 50000;

parameters = {'wStar','w','beta','beta2','theta'};%'alpha'};

%% Initialize the chain
% Initial values of MCMC chains based on data:
wStar = 1/length(wStar_prior) * ones(length(wStar_prior),1);
alpha = 1;
beta = 1;
% Regarding initial values: (1) sigma will tend to be too big if
% the data have outliers, and (2) nu starts at 5 as a moderate value. These
% initial values keep the burn-in period moderate.

% Set initial values for latent variable in each chain
for i=1:nChains
    temp = struct('wStar', wStar, 'alpha',alpha,'beta',1,'w',w);
    initsList(i) = temp;
end


model = fullfile(pwd,'B2WME.txt');

%% Run the chains using matjags and JAGS
% In case you have the Parallel Computing Toolbox, use ('doParallel',1)
[~, ~, mcmcChain] = matjags(...
    dataList,...
    model,...
    initsList,...
    'monitorparams', parameters,...
    'doparallel',1,...
    'nChains', nChains,...
    'nBurnin', burnInSteps,...
    'thin', thinSteps,...
    'verbosity',1,...
    'nSamples',numSavedSteps);


wall = zeros(size(w));
wStarFinal = zeros(size(wStar));
for i=1:nChains
    for j=1:numSavedSteps
        for k=1:size(w,1)
            for l=1:size(w,2)
                wall(k,l) = wall(k,l) + mcmcChain(i).w(j,k,l);
            end
        end
    end
end

```

```
wall = wall / (nChains * numSavedSteps);

mcmcChain = mbe_restructChains(mcmcChain);
mcmcChain = mbe_concChains(mcmcChain);

w_final = [];
for i=1:size(A_B,2)
    w_final = [w_final eval(['mcmcChain.wStar' num2str(i)])];
end


end
```

E.1.2. Matjags

```
function [samples, stats, structArray] = matjags(dataStruct, jagsFilenm, initStructs , varargin)
% MATJAGS, a Matlab interface for JAGS
% Version 1.3.2. Tested on JAGS 3.3.0, Windows 64-bit version
%
% This code has been adapted from MATBUGS that was written by Kevin Murphy and Maryam Mahdaviani
%
% [samples, stats] = matjags(dataStruct,  bugsModelFileName,  initStructs, ...)
%
% INPUT:
% dataStruct contains values of observed variables.
% jagsFilenm is the name of the model file
% initStructs contains initial values for the latent variables (unlike
% matbugs, this is a required variable)

% Note: variables with names 'a.b' in the bugs model file
% should be called 'a_b' in the matlab data structure.
%
% Optional arguments passed as 'string', value pairs [default in brackets, case
% insensitive]:
% 'monitorParams' - cell array of field names (use 'a_b' instead of 'a.b')
%                   [defaults to *, which currently does nothing...]
% 'nChains'  - number of chains [3]
% 'nBurnin'  - num samples for burn-in per chain [1000]
% 'nSamples' - num samples to keep after burn-in [5000]
% 'thin'     - keep every n'th step [1]
% 'dic'      - [1] read out DIC values
% 'workingDir' - directory to store temporary data/init/coda files [pwd/tmp]. Note that total number of iterations  = nBurnin + nSamples * thin.
% 'savejagsoutput' - 0/1 = do/do not produce text files with output from JAGS
% 'verbosity'  -
%    0 = no messages during runtime;
%    1 = minimum number of messages (e.g. which chain is being executed);
%    2 = maximum number of messages
% 'cleanup' - 0/1 -- do we want to remove PREVIOUS temporary files?
% 'dotranspose' - Set to 0 (default) if you want to insure compatibility with matbugs/WinBUGS
%
% OUTPUT
% S contains the samples; each field may have a different shape:
%  S.theta(c, s)       is the value of theta in sample s, chain c
%                      (scalar variable)
%  S.theta(c, s, i)    is the value of theta(i) in sample s, chain c
%                      (vector variable)
%  S.theta(c, s, i, j) is the value of theta(i,j) in sample s, chain c
%                      (matrix variable)
%
% stats contains various statistics, currently:
%    stats.mean, stats.std and stats.Rhat, stats.DIC.
% Each field may have a different shape:
%    stats.mean.theta
%    stats.mean.theta(i)
%    stats.mean.theta(i,j)
%
% Rhat is the "estimated potential scale reduction" statistic due to
%     Gelman and Rubin.
% Rhat values less than 1.1 mean the chain has probably converged for
%     this variable.
%
% Example
%
%     [samples, stats ] = matjags( ...
%         datastruct, ...
%                 fullfile(pwd, 'Gaussian_3.txt'), ...
```

```
%                   init0, ...
%           'doparallel' , 0, ...
%           'nchains', nchains,...
%                   'nburnin', nburnin,...
%           'nsamples', nsamples, ...
%                   'thin', 1, ...
%           'dic' , 1,...
%                   'monitorparams', {'mu','sigma'}, ...
%                   'savejagsoutput' , 1 , ...
%           'verbosity' , 1 , ...
%           'cleanup' , 0 , ...
%           'showwarnings' , 1 , ...
%           'workingdir' , 'tmpjags' );
%
% For Windows users:
% The JAGS executable should be placed in the windows path
% In Windows 7, go to Control Panel, System and Security, System
% and click on "Advanced System Settings" followed by "Environment Variables"
% Under System variables, click on Path, and add the jags path to the string
% This could look something like "C:\Program Files\JAGS\JAGS-4.3.0\x64\bin"
%
% For MAC users:
% Mike Kalish provided some suggestions to make matjags work on a Mac. These were implemented
% in the current version but this code is not thouroughly tested yet. Please send me any changes in
% the code needed to make matjags run on a Mac/Linux/Unix system.
%
% Written by Mark Steyvers (mark.steyvers@uci.edu) based on the code
% MATBUGS that was written by Maryam Mahdaviani (maryam@cs.ubc.ca)
% and Kevin Murphy (murphyk@cs.ubc.ca)

% Changes in version 1.3.2:
% * Bug fix. Fixed issue with initialization of parameter values. All values were set to the value for
% chain 1.

% Changes in version 1.3:
% * Bug fix. Added lines marked by "% GP" as suggested by Ganesh Padmanabhan

% Changes in version 1.1:
% * The warnings produces by JAGS are now suppressed by default. This removes
% any message about adaptation being incomplete due to a small number of
% burnin iterations
% * Changed the default working directory for JAGS to make it platform
% independent



if ispc
    defaultworkingDir = 'c:\temp\jagstmp'; % change this to fit your particular needs
elseif ismac | isunix
    defaultworkingDir = [ '..' filesep 'jagstmp' ]; % change this to fit your particular needs
end

% Get the parameters
[ nChains, workingDir, nBurnin, nSamples, ...
    monitorParams, thin, dodic, doParallel, savejagsoutput, verbosity, cleanup, showwarnings,dotranspose, doboot ] =  ...
    process_options(...
    varargin, ...
    'nChains', 1, ...
    'workingDir', defaultworkingDir, ...
    'nBurnin', 1000, ...
    'nSamples', 5000, ...
    'monitorParams', {}, ...
    'thin', 1, ...
    'dic' , 1, ...
    'doParallel' , 0, ...
    'savejagsoutput' , 1, ...
    'verbosity' , 0,...
    'cleanup' , 0, ...
    'showwarnings' , 0 , ...
    'dotranspose' , 0 );

if length( initStructs ) ~= nChains
    error( 'Number of structures with initial values should match number of chains' );
end

[ whdir , jagsModelBase , modelextension ] = fileparts( jagsFilenm );
jagsModel = [ jagsModelBase modelextension ];

```

```
% get the current directory
curdir = pwd;
cd( whdir );
%[status,result] = dos( 'dir' )

% Does the temporary directory exist? If not, create it
if ~exist( workingDir , 'dir' )
    [SUCCESS,MESSAGE,MESSAGEID] = mkdir(workingDir);
    if SUCCESS == 0
        error( MESSAGE );
    end
end

cd( workingDir );

% Do we want to cleanup files before we start?
if cleanup==1
    delete( 'CODA*' );
    delete( 'jag*' );
end

% Create the data file
jagsData = 'jagsdata.R';
dataGenjags(dataStruct, jagsData , '', dotranspose );


nmonitor = length( monitorParams );
if nmonitor == 0
    error( 'Please specify at least one node name to monitor' );
end

% Develop a separate JAGS script for each chain
for whchain=1:nChains
    jagsScript   = sprintf( 'jagscript%d.cmd' , whchain );
    codastem     = sprintf( 'CODA%d' , whchain );
    InitData     = sprintf( 'jagsinit%d.R' , whchain );

    % Create the jags script for this chain
    [ fid , message ] = fopen( jagsScript , 'wt' );
    if fid == -1
        error( message );
    end

    fprintf( fid , 'load wiener\n' ); % Adding the Wiener Diffusion model
    fprintf( fid , 'load glm\n' );

    %fprintf( fid , 'model in "..%s%s"\n' , filesep , jagsModel' );
    if dodic
        fprintf( fid , 'load dic\n' );
    end

    if ~isempty(whdir) && (strcmp(whdir(1),filesep) || (length(whdir) > 2 && whdir(2) == ':'))
        % Case when a full path string is specified for the jagsModel
        fprintf( fid , 'model in "%s"\n' , fullfile(whdir , jagsModel));
    else
        % Case when a relative path string is specified for the jagsModel
        fprintf( fid , 'model in "%s"\n' , fullfile(curdir , whdir, jagsModel));
    end

    fprintf( fid , 'data in %s\n' , jagsData' );
    fprintf( fid , 'compile, nchains(1)\n' );
    fprintf( fid , 'parameters in %s\n' , InitData );
    fprintf( fid , 'initialize\n' );
    fprintf( fid , 'update %d\n' , nBurnin );
    for j=1:nmonitor
        fprintf( fid , 'monitor set %s, thin(%d)\n' , monitorParams{ j } , thin );
    end
    if dodic
        %fprintf( fid , 'monitor deviance, thin(%d)\n' , thin );
        fprintf( fid , 'monitor deviance\n' );
        %fprintf( fid , 'monitor pD\n' );
    end
    fprintf( fid , 'update %d\n' , nSamples * thin );
    fprintf( fid , 'coda *, stem(''%s'')\n' , codastem );
    fclose( fid );

    % Create the init file
    addlines = { '".RNG.name" <- "base::Mersenne-Twister"' , ...
        sprintf( '".RNG.seed" <- %d' , whchain ) };
```

```
    dataGenjags( initStructs( whchain ), InitData , addlines, dotranspose );
end

% Do we use the Matlab parallel computing toolbox?
if doParallel==1
    %numworkers = matlabpool('size');
    %if (numworkers == 0)
    %    error( 'Matlab pool of workers not initialized. Use command "matlabpool open 7" for example to
        open up a pool of 7 workers' );
    %end

    status = cell( 1,nChains );
    result = cell( 1,nChains );
    if ispc
        parfor whchain=1:nChains
            jagsScript   = sprintf( 'jagscript%d.cmd' , whchain );
            cmd = sprintf( 'jags %s' , jagsScript );
            if verbosity > 0
                fprintf( 'Running chain %d (parallel execution)\n' , whchain  );
            end
            [status{ whchain },result{whchain}] = dos( cmd );
        end
    elseif ismac | isunix
        parfor whchain=1:nChains
            jagsScript   = sprintf( 'jagscript%d.cmd' , whchain );
            jagsPrefix = sprintf('/usr/local/bin/');
            cmd = sprintf( '%sjags %s' ,jagsPrefix, jagsScript );
            if verbosity > 0
                fprintf( 'Running chain %d (parallel execution)\n' , whchain  );
            end
            [status{ whchain },result{whchain}] = dos( cmd );
        end
    end

else % Run each chain serially
    status = cell( 1,nChains );
    result = cell( 1,nChains );
    for whchain=1:nChains
        jagsScript   = sprintf( 'jagscript%d.cmd' , whchain );
        if ispc
            cmd = sprintf( 'jags %s' , jagsScript );
        elseif ismac | isunix
            jagsPrefix = sprintf('/usr/local/bin/');
            cmd = sprintf( '%sjags %s' ,jagsPrefix, jagsScript );
        end
        if verbosity > 0
            fprintf( 'Running chain %d (serial execution)\n' , whchain );
        end
        [status{ whchain },result{whchain}] = dos( cmd );
    end
end

% Save the output from JAGS to a text file?
if savejagsoutput==1
    for whchain=1:nChains
        filenm = sprintf( 'jagoutput%d.txt' , whchain );
        [ fid , message ] = fopen( filenm , 'wt' );
        if fid == -1
            error( message );
        end
        resultnow = result{whchain};
        fprintf( fid , '%s' , resultnow );
        fclose( fid );
    end
end

%% Do some error checking.
% For each chain, check if the output contains some error or warning message.
for whchain=1:nChains
    resultnow = result{whchain};
    statusnow = status{ whchain };
    if status{whchain} > 0
        cd( curdir );
        error( [ 'Error from dos environment: ' resultnow ] );
    end

    % Do we get an error message anywhere from JAGS --> produce an error
    pattern = [ 'can''t|RUNTIME ERROR|syntax error|failed' ];
    errstr = regexpi( resultnow , pattern , 'match' );
```

```
    if ~isempty( errstr )
        cd( curdir );
        fprintf( 'Error encountered in jags (chain %d). Check output from JAGS below:\n' , whchain  );
        fprintf( 'JAGS output for chain %d\n%s\n' , whchain , resultnow );
        error( 'Stopping execution because of jags error' );
    end

    % Do we get a warning message anywhere from JAGS --> produce a matlab warning
    if showwarnings ~= 0
        pattern = [ 'WARNING' ];
        errstr = regexpi( resultnow , pattern , 'match' );
        if ~isempty( errstr )
            warning( 'JAGS produced a warning message. Check the output below produced by the JAGS run' );
            fprintf( 'JAGS output for chain %d\n%s\n' , whchain , resultnow );
        end
    end

    if verbosity == 2
        fprintf( 'JAGS output for chain %d\n%s\n' , whchain , resultnow );
    end


    % NOTE: if the error is "jags is not recognized as an internal or external
    % command, then the jags bin folder is not on the windows path"
end

%% Extract information from the output files so we can pass it back to Matlab
codaIndex = 'CODA1index.txt'; % the index files are identical across chains, just pick first one
for i=1:nChains
    codaF = [ 'CODA' , num2str(i) , 'chain1.txt' ];

    S = bugs2mat(codaIndex, codaF);
    structArray(i) = S;
end
samples = structsToArrays(structArray);
stats = computeStats(samples,doboot);


cd( curdir );

%% DIC calculation
if dodic
    dbar = mean( samples.deviance(:));
    dhat = min( samples.deviance(:));
    pd = dbar - dhat;
    stats.dic = pd + dbar;
end

end

%% ----- nested functions -----------------
function dataGenjags(dataStruct, fileName, addlines, dotranspose )
% This is a helper function to generate data or init files for JAGS
% Inputs:
%   fileName: name of the text file containing initial values. for each
%             chain we'll fileName_i where 'i' is the chain number,
%   dataStruct: is a Struct with name of params(consistant in the same
%               order with paramList) are fields and intial values are functions

if nargin<3
    error(['This function needs three arguments']);
end

fieldNames = fieldnames(dataStruct);
Nparam = size(fieldNames, 1);

%fileName = [fileName, '.txt'];
fid = fopen(fileName, 'w');
if fid == -1
    error(['Cannot open ', fileName ]);
end

%fprintf(fid,'list(');
for i=1:Nparam
    fn = fieldNames(i);
    fval = fn{1};
    val = getfield(dataStruct, fval);
    [sfield1, sfield2]= size(val);

```

```
    msfield = max(sfield1, sfield2);
    newfval = strrep(fval, '_', '.');
    newfval = [ '"' newfval '"' ];

    if ((sfield1 == 1) && (sfield2 == 1))  % if the field is a singleton
        fprintf(fid, '%s <-\n%G',newfval, val);

        %
        % One-D array:
        %   beta = c(6, 6, ...)
        %
        % 2-D or more:
        %   Y=structure(
        %     .Data = c(1, 2, ...), .Dim = c(30,5))
        %
    elseif ((length(size(val)) == 2) && ((sfield1 == 1) || (sfield2 == 1)))
        fprintf(fid, '%s <-\nc(',newfval);
        for j=1:msfield
            if (isnan(val(j)))
                fprintf(fid,'NA');
            else
                % format for winbugs
                fprintf(fid,wb_strval(val(j)));
            end
            if (j<msfield)
                fprintf(fid, ', ');
            else
                fprintf(fid, ')');
            end
        end
    else
        % non-trivial 2-D or more array
        valsize    = size(val);
        alldatalen = prod(valsize);
        %alldata = reshape(val', [1, alldatalen]);
        %alldata = alldata(:)';

        %Truccolo-Filho, Wilson <Wilson_Truccolo@brown.edu>
        if length(valsize)<3
            if dotranspose==0
                alldata = reshape(val, [1, alldatalen]);
            else
                alldata = reshape(val', [1, alldatalen]);
                valsize = size( val' );
            end
        elseif length(valsize)==3
            clear valTransp
            if dotranspose==1
                for j=1:valsize(3)
                    valTransp(j,:,:)=val(:,:,j)';%need a new variable, since val might be rectangular
                end
                alldata=valTransp(:)';
            else % GP
                alldata = reshape(val, [1, alldatalen]); % GP
            end
        else
            ['Error: 4D and higher dimensional arrays not accepted']
            return
        end

        %fprintf(fid, '%s <-\nstructure(.Data=c(', newfval);
        fprintf(fid, '%s <-\nstructure(c(', newfval);
        for j=1:alldatalen
            if (isnan(alldata(j)))
                fprintf(fid,'NA');
            else
                % format for winbugs
                fprintf(fid,wb_strval(alldata(j)));
            end
            if (j < alldatalen)
                fprintf(fid,',');
            else
                fprintf(fid,'), .Dim=c(', alldata(j));
            end
        end

        for j=1:length(valsize)
            if (j < length(valsize))
                fprintf(fid, '%G,', valsize(j));
```

```
            else
                fprintf(fid, '%G))', valsize(j));
            end
        end
    end
    if (i<Nparam)
        %fprintf(fid, ', ');
        fprintf(fid, '\n');
    else
        %fprintf(fid, ')\n');
        fprintf(fid, '\n');
    end
end

if length( addlines ) > 0
    nextra = length( addlines );
    for j=1:nextra
        fprintf( fid , '%s\n' , addlines{ j } );
    end
end

fclose(fid);

%%%%%%%%
end

function s = wb_strval(v)
% Converts numeric value to a string that is acceptable by winbugs.
% This is most problematic for exponent values which must have at least 1
% decimal and two digits for the exponent. So 1.0E+01 rather than 1E+001
% Note that only Matlab on PC does 3 digits for exponent.
s = sprintf('%G', v);
if strfind(s, 'E')
    if length(strfind(s, '.')) == 0
        s = strrep(s, 'E', '.0E');
    end
    s = strrep(s, 'E+0', 'E+');
    s = strrep(s, 'E-0', 'E-');
end

%%%%%%%%
end
function f = fullfileKPM(varargin)
% fullfileKPM Concatenate strings with file separator, then convert it to a/b/c
% function f = fullfileKPM(varargin)

f = fullfile(varargin{:});
f = strrep(f, '\', '/');

%%%%%%%%
end
function A = structsToArrays(S)
% Suppose S is this struct array
%
% S(c).X1(s)
% S(c).X2(s,i)
% S(c).X3(s,i,j)
%
% where s=1:N in all cases
%
% Then we return
% A.X1(c,s)
% A.X2(c,s,i)
% A.X3(c,s,i,j)

C = length(S);
fld = fieldnames(S);
A = [];
for fi=1:length(fld)
    fname = fld{fi};
    tmp = getfield(S(1), fname);
    sz = size(tmp);
    psz = prod(sz);
    data = zeros(C, psz);
    for c=1:C
        tmp = getfield(S(c), fname);
        %data = cat(1, data, tmp);
        data(c,:) = tmp(:)';
    end
```

```
    if sz(2) > 1 % vector or matrix variable
        data = reshape(data, [C sz]);
    end
    A = setfield(A, fname, data);
end

end
%%%%%%%%%%%%

function [Rhat, m, s] = EPSR(samples)
%
% function [R, m, s] = EPSR(samples)
% "estimated potential scale reduction" statistics due to Gelman and Rubin.
% samples(i,j) for sample i, chain j
%
% R = measure of scale reduction - value below 1.1 means converged:
%                                   see Gelman p297
% m = mean(samples)
% s = std(samples)

% This is the same as the netlab function convcalc(samples')

[n m] = size(samples);
meanPerChain = mean(samples,1); % each column of samples is a chain
meanOverall = mean(meanPerChain);

% Rhat only works if more than one chain is specified.
if m > 1
    % between sequence variace
    B = (n/(m-1))*sum( (meanPerChain-meanOverall).^2);

    % within sequence variance
    varPerChain = var(samples);
    W = (1/m)*sum(varPerChain);

    vhat = ((n-1)/n)*W + (1/n)*B;
    Rhat = sqrt(vhat/(W+eps));
else
    Rhat = nan;
end

m = meanOverall;
s = std(samples(:));

%%%%%%%%%
end
function stats = computeStats(A,doboot)

fld = fieldnames(A);
N = length(fld);
stats = struct('Rhat',[], 'mean', [], 'std', [], 'ci_low' , [] , 'ci_high' , [] );
for fi=1:length(fld)
    fname = fld{fi};
    samples = getfield(A, fname);
    sz = size(samples);
    clear R m s
    % samples(c, s, i,j,k)
    Nchains = sz(1);
    Nsamples = sz(2);

    st_mean_per_chain = mean(samples, 2);
    st_mean_overall   = mean(st_mean_per_chain, 1);


    % "estimated potential scale reduction" statistics due to Gelman and
    % Rubin.
    if Nchains > 1
        B = (Nsamples/(Nchains-1)) * ...
            sum((st_mean_per_chain - repmat(st_mean_overall, [Nchains,1])).^2);
        varPerChain = var(samples, 0, 2);
        W = (1/Nchains) * sum(varPerChain);
        vhat = ((Nsamples-1)/Nsamples) * W + (1/Nsamples) * B;
        Rhat = sqrt(vhat./(W+eps));
    else
        Rhat = nan;
    end

    % reshape and take standard deviation over all samples, all chains
    samp_shape = size(squeeze(st_mean_overall));
```

```
    % padarray is here http://www.mathworks.com/access/helpdesk/help/toolbox/images/padarray.html
    %reshape_target = padarray(samp_shape, [0 1], Nchains * Nsamples, 'pre');
    reshape_target = [Nchains * Nsamples, samp_shape]; % fix from Andrew Jackson  a.jackson@tcd.ie
    reshaped_samples = reshape(samples, reshape_target);
    st_std_overall = std(reshaped_samples);

    % get the 95% interval of the samples (not the mean)
    ci_samples_overall = prctile( reshaped_samples , [ 2.5 97.5 ] , 1 );
    ci_samples_overall_low = ci_samples_overall( 1,: );
    ci_samples_overall_high = ci_samples_overall( 2,: );

    if ~isnan(Rhat)
        stats.Rhat = setfield(stats.Rhat, fname, squeeze(Rhat));
    end

    % special case - if mean is a 1-d array, make sure it's long
    squ_mean_overall = squeeze(st_mean_overall);
    st_mean_size = size(squ_mean_overall);
    if (length(st_mean_size) == 2) && (st_mean_size(2) == 1)
        stats.mean = setfield(stats.mean, fname, squ_mean_overall');
    else
        stats.mean = setfield(stats.mean, fname, squ_mean_overall);
    end

    stats.std = setfield(stats.std, fname, squeeze(st_std_overall));

    stats.ci_low = setfield(stats.ci_low, fname, squeeze(ci_samples_overall_low));
    stats.ci_high = setfield(stats.ci_high, fname, squeeze(ci_samples_overall_high));
end
end


%%%%%%%%%%%%
% Andrew Jackson - function getDICstats added a.jackson@tcd.ie
% Used to retrieve the DIC statistics from the log file
% if matbugs input DICstatus = 1
% This code is probably a bit clunky but it does the job.
% Note that the values read from the log file have 3 decimal places but
% matlab decides to give them 4 - with a zero tagged on the end. The
% precision is obviously only to 3 decimal places. sscanf.m does not seem
% to recognise the field-width and precision codes that sprintf.m does.
function DICstats = getDICstats(workingDir)
DICstats = [];
FIDlog = fopen([workingDir '\log.txt'],'r');
ct = 0;
test = 0;
endloop = 0;
while 1

    tline = fgets(FIDlog);

    if tline == -1; break; end
    if endloop; break; end

    if strfind(tline,'dic.set cannot be executed');
        DICstats.error = 'DIC monitor could not be set by WinBUGS';
    end

    if size(tline,2)>6
        % The string 'total' in the log file denotes the end of the DIC
        % stats so the loop can be ended in the next iteration.
        if strcmp(tline(1:5),'total'); endloop = 1; end;
    end

    if size(tline,2)>2
        % locate the DIC string identifier in the log file
        if strcmp(tline(1:3),'DIC'); test = 1; end
    end

    if test
        ct=ct+1;
        % DIC results are located 3 lines after the DIC string identifier
        % in the log file.
        if ct >= 4
            A = sscanf(tline,'%*s %f %f %f %f');
            S = sscanf(tline, '%s %*f %*f %*f %*f');
            % Cheng-Ta, Yang suggested this change
            %DICstats = setfield(DICstats,S,'Dbar',A(1));
            %%DICstats = setfield(DICstats,S,'Dhat',A(2));
```

```
            %DICstats = setfield(DICstats,S,'pD',A(3));
            %DICstats = setfield(DICstats,S,'DIC',A(4));
            DICstats.S.Dbar = A(1);
            DICstats.S.Dhat = A(2);
            DICstats.S.pD = A(3);
            DICstats.S.DIC = A(4);
            DICstats.S.Dhat = A(2);
        end
    end
end

fclose(FIDlog)
end

%%%%%%%%%%%%

function S=bugs2mat(file_ind,file_out,dir)
%BUGS2MAT  Read (Win)BUGS CODA output to matlab structure
%
% S=bugs2mat(file_ind,file_out,dir)
%  file_ind - index file (in ascii format)
%  file_out - output file (in ascii format)
%  dir      - directory where the files are found (optional)
%  S        - matlab structure, with CODA variables as fields
%
% The samples are stored in added 1'st dimension,
% so that 2 x 3 variable R with 1000 samples would be
% returned as S.R(1000,2,3)
%
% Note1: the data is returned in a structure that makes extraction
% of individual sample sequencies easy: the sequencies are
% directly Nx1 double vectors, as for example S.R(:,1,2).
% The computed statistics must, however, be squeezed,
% as mean(S.R,1) is a 1x2x2 matrix.
%
% Note2: in variable names "." is replaced with "_"

% To change the output structure, edit the 'eval' line in the m-file.
% For example, to return all samples as a cell, wich possibly varying
% number of samples for elements of a multidimensional variable,
% cange the 'eval' line to
%    eval(['S.' varname '={samples};']);
% Then the samples of R(2,1) would be returned as cell S.R(2,1)

% (c) Jouko.Lampinen@hut.fi, 2000
% 2003-01-14 Aki.Vehtari@hut.fi - Replace "." with "_" in variable names
% slightly modified by Maryam Mahdaviani, August 2005 (to suppress redundant output)

if nargin>2,
    file_ind=[dir '/' file_ind];
    file_out=[dir '/' file_out];
end

ind=readfile(file_ind);

data=load(file_out);

Nvars=size(ind,1);
S=[];
for k=1:Nvars
    [varname,indexstr]=strtok(ind(k,:));
    varname=strrep(varname,'.','_');
    indices=str2num(indexstr);
    if size(indices)~=[1 2]
        error(['Cannot read line: [' ind(k,:) ']']);
    end
    sdata = size(data);
    %indices
    samples=data(indices(1):indices(2),2);
    varname(varname=='[')='(';
    varname(varname==']')=')';
    leftparen=find(varname=='(');
    outstruct=varname;
    if ~isempty(leftparen)
        outstruct=sprintf('%s(:,%s',varname(1:leftparen-1),varname(leftparen+1:end));
    end
    eval(['S.' outstruct '=samples;']);
end
end
```

```
function T=readfile(filename)
f=fopen(filename,'r');
if f==-1, fclose(f); error(filename); end
i=1;
while 1
    clear line;
    line=fgetl(f);
    if ~isstr(line), break, end
    n=length(line);
    T(i,1:n)=line(1:n);
    i=i+1;
end
fclose(f);
end

% PROCESS_OPTIONS - Processes options passed to a Matlab function.
%                   This function provides a simple means of
%                   parsing attribute-value options.  Each option is
%                   named by a unique string and is given a default
%                   value.
%
% Usage:  [var1, var2, ..., varn[, unused]] = ...
%           process_optons(args, ...
%                           str1, def1, str2, def2, ..., strn, defn)
%
% Arguments:
%            args            - a cell array of input arguments, such
%                              as that provided by VARARGIN.  Its contents
%                              should alternate between strings and
%                              values.
%            str1, ..., strn - Strings that are associated with a
%                              particular variable
%            def1, ..., defn - Default values returned if no option
%                              is supplied
%
% Returns:
%            var1, ..., varn - values to be assigned to variables
%            unused          - an optional cell array of those
%                              string-value pairs that were unused;
%                              if this is not supplied, then a
%                              warning will be issued for each
%                              option in args that lacked a match.
%
% Examples:
%
% Suppose we wish to define a Matlab function 'func' that has
% required parameters x and y, and optional arguments 'u' and 'v'.
% With the definition
%
%   function y = func(x, y, varargin)
%
%     [u, v] = process_options(varargin, 'u', 0, 'v', 1);
%
% calling func(0, 1, 'v', 2) will assign 0 to x, 1 to y, 0 to u, and 2
% to v.  The parameter names are insensitive to case; calling
% func(0, 1, 'V', 2) has the same effect.  The function call
%
%   func(0, 1, 'u', 5, 'z', 2);
%
% will result in u having the value 5 and v having value 1, but
% will issue a warning that the 'z' option has not been used.  On
% the other hand, if func is defined as
%
%   function y = func(x, y, varargin)
%
%     [u, v, unused_args] = process_options(varargin, 'u', 0, 'v', 1);
%
% then the call func(0, 1, 'u', 5, 'z', 2) will yield no warning,
% and unused_args will have the value {'z', 2}.  This behaviour is
% useful for functions with options that invoke other functions
% with options; all options can be passed to the outer function and
% its unprocessed arguments can be passed to the inner function.

% Copyright (C) 2002 Mark A. Paskin
% GNU GPL
function [varargout] = process_options(args, varargin)
```

```
% Check the number of input arguments
n = length(varargin);
if (mod(n, 2))
    error('Each option must be a string/value pair.');
end

% Check the number of supplied output arguments
if (nargout < (n / 2))
    error('Insufficient number of output arguments given');
elseif (nargout == (n / 2))
    warn = 1;
    nout = n / 2;
else
    warn = 0;
    nout = n / 2 + 1;
end

% Set outputs to be defaults
varargout = cell(1, nout);
for i=2:2:n
    varargout{i/2} = varargin{i};
end

% Now process all arguments
nunused = 0;
for i=1:2:length(args)
    found = 0;
    for j=1:2:n
        if strcmpi(args{i}, varargin{j})
            varargout{(j + 1)/2} = args{i + 1};
            found = 1;
            break;
        end
    end
    if (~found)
        if (warn)
            warning(sprintf('Option ''%s'' not used.', args{i}));
            args{i}
        else
            nunused = nunused + 1;
            unused{2 * nunused - 1} = args{i};
            unused{2 * nunused} = args{i + 1};
        end
    end
end

% Assign the unused arguments
if (~warn)
    if (nunused)
        varargout{nout} = unused;
    else
        varargout{nout} = cell(0);
    end
end
end
```

E.1.3. mbeconChains

```
    function mcmcChainOut = mbe_concChains(mcmcChain)
%% mbe_concChains
%   Concatenate several MCMC chains into one.
%
% INPUT:
%   mcmcChain
%       is a structure containing one structure for every MCMC chain.
%       This is the default output of matjags.
%
% OUTPUT:
%   mcmcChainOut
%       one structure with fields for every parameter
%
% EXAMPLE:
%   mcmcChainOut = mbe_concChains(mcmcChains);

% Nils Winter (nils.winter1@gmail.com)
% Johann-Wolfgang-Goethe University, Frankfurt
% Created: 2016-03-15
```

```
% Version: v1.2 (2016-04-12)
% Matlab 8.1.0.604 (R2013a) on PCWIN
%-------------------------------------------------------------------------

% get names
names = fieldnames(mcmcChain(1,1));

% preallocate
for indNames = 1:numel(names)
    mcmcChainOut.(names{indNames}) = [];
end

% concatenate chains
for indNames = 1:size(names,1)
    for indChain = 1:size(mcmcChain.(names{1}),2)
        mcmcChainOut.(names{indNames}) = [mcmcChainOut.(names{indNames});...
            mcmcChain.(names{indNames})(:,indChain,:)];
    end
end

end
```

E.1.4. mberestructchains

```
    function mcmcChainOut = mbe_restructChains(mcmcChain)
%% mbe_restructChains
%   Restructures MCMC output (of matjags). Matjags creates multiple
%   structures when more than one chain is used, but stores parameters
%   with the same name in the same variable. This function splits up
%   the parameters and creates one structure with all the monitored
%   parameters. Parameters are stored as matrix with NxMxT, where N is
%   the number of iterations per chain, M is the number of chains and T is
%   the number of time steps (only for time course analysis).
%
% INPUT:
%   mcmcChain
%       - structure containing the chains (default output created by
%           matjags)
%   or mcmcChainTs
%       - cell array containing one mcmcChain structure per time point
%
% OUTPUT:
%   mcmcChainOut
%       - structure with one field for every parameter
%
% EXAMPLE:

% Nils Winter (nils.winter1@gmail.com)
% Johann-Wolfgang-Goethe University, Frankfurt
% Created: 2016-03-30
% Version: v1.2 (2016-04-12)
%-------------------------------------------------------------------------

% Check if input is time series of multiple mcmc simulations or not
% Input is ts (multiple mcmc simulations with multiple chains)
if iscell(mcmcChain)
    % Get parameter names
    names = fieldnames(mcmcChain{1});
    pNames = {};
    cnt = 1;
    for indField = 1:(numel(names)-1)  % -1 to skip 'deviance' parameter
        for indParam = 1:size(mcmcChain{1}(1).(names{indField}),2)
            pNames{cnt} = [names{indField} num2str(indParam)];
            cnt = cnt+1;
        end
    end

    % Get parameters
    cnt = 1;
    for indTime = 1:size(mcmcChain,2)
        for indChain = 1:size(mcmcChain{1},2)
            for indField = 1:(numel(names)-1)  % -1 to skip 'deviance' parameter
                for indParam = 1:size(mcmcChain{1}(1).(names{indField}),2)
                    mcmcChainOut.(pNames{cnt})(:,indChain,indTime) = mcmcChain{indTime}(indChain).(names{
                        indField})(:,indParam);
                    cnt = cnt+1;
                end
```

```
            end
            cnt = 1;
        end
    end


% input is just one time step with one or more chains
elseif isstruct(mcmcChain)
    % Get parameter names
    names = fieldnames(mcmcChain(1));
    pNames = {};
    cnt = 1;
    for indField = 1:(numel(names)-1)  % -1 to skip 'deviance' parameter
        for indParam = 1:size(mcmcChain(1).(names{indField}),2)
            pNames{cnt} = [names{indField} num2str(indParam)];
            cnt = cnt+1;
        end
    end

    % Get parameters
    cnt = 1;
    for indChain = 1:size(mcmcChain,2)
        for indField = 1:(numel(names)-1)  % -1 to skip 'deviance' parameter
            for indParam = 1:size(mcmcChain(1).(names{indField}),2)
                mcmcChainOut.(pNames{cnt})(:,indChain) = mcmcChain(indChain).(names{indField})(:,indParam);
                cnt = cnt+1;
            end
        end
        cnt = 1;
    end

else
    error(['Input must be either structure with mcmc chains (matjags output) '...
        'or a cell array containing multiple mcmc chains (i.e. for ERP analysis).']);
end
```

E.1.5. Graph Plot

```
    function [probability]  = plotGraph(w,labels)

w_opt = mean(w);
[sampleNo,criteriaNo] = size(w);

probability = zeros(size(w,2));

for i=1:size(w,2)
   for j=1:size(w,2)
      probability(i,j) = length(find(w(:,i) > w(:,j))) / sampleNo;
   end
end


nonZeroProb = length(find(probability > 0.5));
edgeTable = zeros(nonZeroProb,3);
counter = 1;
for i=1:size(probability,1)
    for j=1:size(probability,1)
        if probability(i,j) > 0.5
           edgeTable(counter,:) = [i j probability(i,j)];
           counter = counter+1;
        end
    end
end

finalProb = zeros(size(probability));
finalProb(probability > 0.5) = probability(probability > 0.5);

directedGraph = probability > 0.5;

set(0,'defaultAxesFontSize', 12,'defaultAxesFontWeight','b')
G = digraph(directedGraph);
p = plot(G,'k','NodeLabel',labels,'EdgeLabel',round(edgeTable(:,3),2));
p.Marker = 's';
p.NodeColor = 'r';
p.MarkerSize = 7;
%p.LineStyle = '--';
axis off
```

```
NameArray = {'linewidth','markersize'};
ValueArray ={1.8,10};
set(p,NameArray,ValueArray);
set(gcf,'color','w');

p.NodeLabel = '';
xd = get(p, 'XData');
yd = get(p, 'YData');
text(xd, yd, labels, 'FontSize',12, 'FontWeight','bold', 'HorizontalAlignment','right', 'VerticalAlignment','bottom')

C = {[0 255     255]/255,'r','g','b',[238 154 0]/255,[139 58 58]/255,[.2 .5 .7],[.6 .2 .7],[255 0 255]/255,[.5 .7 .2]};
C = C(1:criteriaNo);
for j=1:length(labels)
    T = [];
    for i=1:size(G.Edges.EndNodes,1)
        if G.Edges.EndNodes(i,1) == j
           %T = [T;G.Edges.EndNodes(j,1:2)];
            highlight(p,G.Edges.EndNodes(i,1:2),'EdgeColor',C{j},'LineWidth',1.5)
        end
    end

end

end
```

E.1.6. Layer 1 Matrices

```
    %A_B is the matrix whose rows are the best-to-others vector of each
%            decision maker

nameOfCriteria = {'Blockchain','Stakeholder','Data'};
A_B = [6 9 1;
       7 1 9;
       9 1 6;
       9 8 1;
       7 3 1;
       5 8 1;
       8 1 7;
       9 5 1;
       8 5 1;
       8 1 7;
       5 9 1;
       7 1 3;];

%A_B is the matrix whose rows are the others-to-worst vector of each
%decision maker
A_W = [ 4      1      9;
        7      9      1;
        1      8      6;
        1      8      9;
        1      4      8;
        4      1      7;
        1      7      5;
        1      6      9;
        1      5      9;
        1      9      5;
        7      1      9;
        1      7      6;];


 [w_final,wall] = BayesianBWM(A_B,A_W);

 averageWeight_layer1 = mean(w_final)

 probability_layer1 = plotGraph(w_final,nameOfCriteria)
```

E.1.7. Data Matrices

```
    %A_B is the matrix whose rows are the best-to-others vector of each
%            decision maker

nameOfCriteria = {'Access Control','Integrity','Ownership', 'Confidentiality'};
A_B = [9 1 1 1;
       8 1 9 6;
```

```
       7 1 6 6;
       9 7 8 1;
       1 1 1 2;
       1 7 1 3;
       6 1 8 6;
       1 8 5 9;
       1 7 1 5;
       1 4 7 4;
       1 9 4 2;
       4 1 5 3;];

%A_B is the matrix whose rows are the others-to-worst vector of each
%decision maker
A_W = [ 1     9     6     6;
        7     9     1     5;
        1     8     6     6;
        1     7     8     9;
        3     2     2     1;
        9     1     9     7;
        5     9     1     5;
        9     2     6     1;
        6     1     7     5;
        9     5     1     7;
        9     1     4     7;
        7     9     1     6;];


 [w_final,wall] = BayesianBWM(A_B,A_W);

 averageWeight_data = mean(w_final)

 probability_data = plotGraph(w_final,nameOfCriteria)
```

E.1.8. Confidentiality Matrices

```
    %A_B is the matrix whose rows are the best-to-others vector of each
%           decision maker

nameOfCriteria = {'Financial Confidentiality','IP Confidentiality'};
A_B = [1 1;
       1 8;
       1 5;
       7 1;
       1 1;
       7 1;
       1 6;
       1 5;
       2 1;
       1 4;
       1 1;
       1 7;];

%A_B is the matrix whose rows are the others-to-worst vector of each
%decision maker
A_W = [ 1     1;
        9     1;
        5     1;
        1     9;
        1     1;
        1     6;
        6     1;
        5     1;
        1     4;
        8     1;
        1     1;
        5     1;];


 [w_final,wall] = BayesianBWM(A_B,A_W);

 averageWeight_confidentiality = mean(w_final)

 probability_confidentiality = plotGraph(w_final,nameOfCriteria)
```

E.1.9. Stakeholder Matrices

```
    %A_B is the matrix whose rows are the best-to-others vector of each
%           decision maker

nameOfCriteria = {'Awareness','Benefit Equality', 'Compliance','Legitimacy','Neutrality','Trust','Growth'};
A_B = [6 3 1 1 1 2 8;
       6 9 8 7 6 1 4;
       7 6 6 6 1 5 7;
       6 2 8 7 5 1 9;
       8 3 1 2 1 1 7;
       9 4 2 2 3 1 8;
       9 3 2 1 1 1 6;
       6 6 3 1 1 3 9;
       5 1 4 4 7 2 2;
       6 5 5 6 7 1 8;
       5 4 6 3 2 1 7;
       9 5 2 2 1 1 7;];

%A_B is the matrix whose rows are the others-to-worst vector of each
%decision maker
A_W = [ 2 6 7 9 9 8 1;
        5 1 8 7 6 9 3;
        1 5 6 6 8 7 5;
        9 2 9 8 4 9 1;
        1 5 8 8 9 9 5;
        1 6 7 7 7 9 3;
        1 6 7 7 7 9 3;
        3 3 3 9 9 6 1;
        4 9 4 5 1 7 7;
        7 7 8 6 6 9 1;
        3 4 5 6 5 9 1;
        1 3 8 8 9 9 3;];


 [w_final,wall] = BayesianBWM(A_B,A_W);

 averageWeight_stakeholder = mean(w_final)

 probability_stakeholder = plotGraph(w_final,nameOfCriteria)
```

E.1.10. Benefit Equality Matrices

```
    %A_B is the matrix whose rows are the best-to-others vector of each
%           decision maker

nameOfCriteria = {'Fair Value Distribution','Gaining Competitive Advantage'};
A_B = [1 1;
       4 1;
       1 9;
       7 1;
       1 1;
       1 1;
       1 1;
       1 8;
       2 1;
       2 1;
       1 1;
       1 6;];

%A_B is the matrix whose rows are the others-to-worst vector of each
%decision maker
A_W = [ 1 1;
        1 9;
        2 1;
        1 6;
        1 1;
        1 1;
        1 1;
        1 9;
        1 4;
        1 4;
        1 1;
        3 1;];


 [w_final,wall] = BayesianBWM(A_B,A_W);

 averageWeight_benefit = mean(w_final)
```

```
probability_benefit = plotGraph(w_final,nameOfCriteria)
```

E.1.11. Neutrality Matrices

```
    %A_B is the matrix whose rows are the best-to-others vector of each
%            decision maker

nameOfCriteria = {'Legislative Neutrality','Executive Neutrality','Arbitrage Neutrality'};
A_B = [1 3 2;
       7 1 9;
       2 1 4;
       1 2 4;
       1 9 7;
       1 5 5;
       1 9 7;
       1 1 4;
       6 1 4;
       5 1 4;
       1 1 5;
       3 1 4;];

%A_B is the matrix whose rows are the others-to-worst vector of each
%decision maker
A_W = [ 3 1 2;
        3 9 1;
        3 4 1;
        3 2 1;
        6 1 5;
        5 5 1;
        9 1 7;
        3 5 1;
        3 7 1;
        1 5 4;
        5 5 1;
        5 6 1;];


 [w_final,wall] = BayesianBWM(A_B,A_W);

 averageWeight_neutrality = mean(w_final)

 probability_neutrality = plotGraph(w_final,nameOfCriteria)
```

E.1.12. Growth Matrices

```
    %A_B is the matrix whose rows are the best-to-others vector of each
%            decision maker

nameOfCriteria = {'Network Effects','Stakeholder Representation'};
A_B = [1 1;
       1 5;
       7 1;
       5 1;
       5 1;
       1 1;
       1 6;
       1 6;
       1 6;
       1 6;
       1 1;
       2 1;];

%A_B is the matrix whose rows are the others-to-worst vector of each
%decision maker
A_W = [ 1 1;
        9 1;
        1 4;
        1 4;
        1 4;
        1 1;
        4 1;
        4 1;
        2 1;
        2 1;
        1 1;
```

```
        1 2;];


 [w_final,wall] = BayesianBWM(A_B,A_W);

 averageWeight_growth = mean(w_final)

 probability_growth = plotGraph(w_final,nameOfCriteria)
```

E.1.13. Blockchain Matrices

```
    %A_B is the matrix whose rows are the best-to-others vector of each
%            decision maker

nameOfCriteria = {'Security','Tangebility', 'Ease of Use & Understandability', 'Sustainability', '
    Compatibility', 'Adaptability'};
A_B = [1 1 5 5 3 9;
       1 6 9 4 5 7;
       5 6 7 5 1 6;
       8 1 8 9 9 6;
       1 1 9 4 6 1;
       3 4 5 3 1 3;
       4 6 6 1 2 2;
       9 1 7 2 5 1;
       2 7 1 3 5 2;
       1 2 4 4 3 2;
       2 1 4 6 2 3;
       1 9 7 5 8 6;];

%A_B is the matrix whose rows are the others-to-worst vector of each
%decision maker
A_W = [ 9 9 4 6 9 1;
        9 6 1 4 5 7;
        7 7 1 5 7 7;
        1 9 7 1 1 6;
        6 7 1 5 5 7;
        7 6 1 7 9 7;
        5 1 1 8 5 4;
        1 9 4 8 5 9;
        6 1 7 4 3 5;
        7 3 3 1 4 6;
        8 9 3 1 8 8;
        9 1 3 3 4 6;];


 [w_final,wall] = BayesianBWM(A_B,A_W);

 averageWeight_blockchain = mean(w_final)

 probability_blockchain = plotGraph(w_final,nameOfCriteria)
```

E.1.14. Legitimacy Matrices

```
    %A_B is the matrix whose rows are the best-to-others vector of each
%            decision maker

nameOfCriteria = {'Involvement of Authorities','Invovlement of Regulations'};
A_B = [1 1;
       7 1;
       1 7;
       6 1;
       1 2;
       1 1;
       1 1;
       3 1;
       1 1;
       1 1;
       1 6;
       1 1;];

%A_B is the matrix whose rows are the others-to-worst vector of each
%decision maker
A_W = [ 1 1;
        1 9;
        3 1;
        1 6;
```

```
        2 1;
        1 1;
        1 1;
        1 5;
        1 1;
        1 4;
        4 1;
        1 1;];


[w_final,wall] = BayesianBWM(A_B,A_W);

averageWeight_benefit = mean(w_final)

probability_benefit = plotGraph(w_final,nameOfCriteria)
```