Gabriel Vega

A Blockchain-based Mobility as a Service concept design with the adoption of Autonomous Vehicles.

An exploratory study of the most elemental systems, requirements and possible configurations.

TU Delft

A Blockchain-based Mobility as a Service concept design with the adoption of Autonomous Vehicles.

An exploratory study of the most elemental systems, requirements, and possible configurations.

By

Gabriel Vega
Student number: 4852613

in partial fulfillment of the requirements for the degree of

Master of Science
in **Complex Systems Engineering and Management**

at the Delft University of Technology,
to be defended publicly on Monday, September 21, 2020, at 11:30 AM.

Chair:	Prof.dr.ir. M.F.W.H.A. (Marijn) Janssen	TU Delft, ICT
First Supervisor:	Drs. J. (Jolien) Ubacht	TU Delft, ICT
Second Supervisor:	Dr. J.A. (Jan Anne) Annema	TU Delft, TLO

Preface

This research thesis represents the last part of my Master's degree in Complex Systems Engineering and Management at Delft University of Technology. Being an Industrial Engineer from Chile, it was an interesting topic for my thesis to explore a Blockchain-based Mobility as a Service concept system with the adaption of Autonomous Vehicles. This is motivated by my interest in technology and its interaction with society. I am very enthusiastic about mobility services and innovative technologies; they are relevant to the future of mobility and the automotive industry. I believe that a big change is coming in the automotive and transport industries and I would love to be a part of it.

I would like to extend my gratitude to all the people that make this thesis research project possible. First and foremost, I would like to thank Jolien Ubacht who guided me very actively as my thesis supervisor. Our weekly meetings provided me with great help and guidance during all the process of developing my thesis. Also, I would like to thanks the group of experts that helped me by providing great feedback for this research. In this regard, I would like to thank the help of Sélinde van Engelenburg for her knowledge of Blockchain and GDPR concerns. Moreover, I would like to thank Prof. Marijn Janssen for providing me his point of view with great expertise and experience regarding the reference architecture and models for this research. Next, I would like to thank Patrick Fahim for his contributions regarding autonomous technologies and positive feedback. Finally, I like to extend my gratitude for my sponsor Comision Nacional de Investigacion Cientifica y Tecnologica (CONICYT) for their financial support that enabled me to realize my studies at TUDelft.

I would like to thanks all my friends and family for their support. Especially during the disturbing times amid a global pandemic from the COVID19 virus. They helped me to get distracted and stay positive during these hard and unusual times.

Gabriel Vega
Delft, August 2020

Table of Contents

Preface 3
Table of Contents 4
Abstract 6
1. Introduction 7
1.1. Technology change in the automotive industry 7
1.2. Mobility as a Service 8
1.3. Autonomous Vehicles, Mobility as a Service and Blockchain 8
1.4. Knowledge gap 9
1.5. Scope 10
1.6. Problem definition 11
1.6.1. Scientific contribution 12
1.6.2. Societal contributions 12
2. Research design 14
2.1. Research Objective and research question 14
2.2. Research approach and methods 14
2.2.1. Sub-questions 15
2.2.2. Research flow 16
3. System description 18
3.1. Technical analysis 18
3.1.1. Mobility as a Service 18
3.1.2. Core characteristics 19
3.1.3. Key functionalities 20
3.2. Institutional analysis 21
3.2.1. GDPR 21
3.2.2. Institutional assumptions 23
3.3. Stakeholder analysis 23
3.3.1. MaaS provider 23
3.3.2. Transport provider 24
3.3.3. Data provider 24
3.3.4. Insurance provider 24
3.3.5. User 25
3.4. Conclusions 25
4. Requirements 27
4.1. Artefacts 27
4.2. Requirement Engineering 27
4.2.1. Requirements elicitation and analysis 28
4.2.2. Requirements specification 29
4.2.3. Requirement validation 33
4.3. Conclusions 33
5. System design and develop 34
5.1. Imagine and Brainstorm 34
5.2. Assess and Select 35
5.2.1. Consensus mechanism 35
5.2.2. Transaction capabilities 36
5.2.3. Native currency/tokenization 37
5.2.4. Extensibility 37
5.2.5. Security and Privacy 38
5.2.6. Identity Management 39
5.2.7. Charging and Rewarding System 39

5.2.8. Design decisions overview 40
5.3. Sketch and Build 41
5.3.1. BC Architecture 41
5.4. Design justifications and rationale 43
5.5. Conclusions 44
6. System demonstration 45
6.1. Business processes 45
6.1.1. Account creation 46
6.1.2. Planning and Booking 47
6.1.3. Ticketing 48
6.1.4. Payment 49
6.2. Reference architecture 50
6.2.1. Business Layer 53
6.2.2. Application Layer 53
6.2.3. Technology Layer 54
6.3. Conclusions 55
7. System evaluation 56
7.1. Evaluation plan 56
7.2. Expert evaluation 57
7.3. Corrections 58
7.4. Conclusions 60
8. Conclusions and reflection 61
8.1. Conclusions 61
8.2. Scientific relevance 63
8.3. Societal relevance 63
8.4. Reflection 64
8.4.1. Limitations 64
8.4.2. Future Research 65
8.5. Link with CoSEM programme 66
Appendices 67
Appendix A 67
Literature Review A 67
Appendix B 69
Literature Review B 69
Appendix C 72
Expert evaluation 72
References 77

Abstract

Autonomous vehicles have the potential to introduce numerous changes, opportunities, and innovations in mobility services, environment, data, value networks, and economy, among others. These automated vehicles are expected to impulse a disruptive change in society, especially within transport technology economics, travel behavior, and network performance. This introduces new challenges and opportunities for the automotive industry and society. Mobility as a Service could take a significant role in the utilization of autonomous vehicles, especially with the current downwards tendency of car ownership in Europe and North America. The scientific literature and consultancy firms reinforce this by providing analysis and predicting a decline of car ownership in the global markets. Nevertheless, there is a need for trust and more secure and tamper-resilient processes within autonomous vehicles and Mobility as a Service ecosystems. Because of this, the idea of this research is to explore what a Blockchain-based Mobility-as-a-Service concept design operated by Autonomous Vehicles would look like, elemental systems, requirements, and possible configurations. This research is conducted from a complex socio-technical point of view that considers a Design Science Research methodology. By doing so, a set of requirements are developed to create a Blockchain architecture, business processes and a reference architecture that will serve as a proof of concept of how a Blockchain-based Mobility-as-a-Service concept design operated by Autonomous Vehicles would look like. Later the artefacts and the process realized in this research are evaluated through a semi-structured interview process. By doing so, some corrections were included in the final design but in general positive impression were given by the experts. This research could be useful to have a first approach on the requirements, BC architecture, business processes and reference architecture of a Blockchain-based Mobility-as-a-Service concept design operated by Autonomous Vehicles. In this regard, Mobility as a Service operators could find this research helpful to start creating or implementing such a system.

1. Introduction

1.1. Technology change in the automotive industry

Vehicles are widely available means of transportation that give access to their users to adaptable and comfortable personal mobility. Nevertheless, their overuse in the last decades has led to an increased ecological impact and different social issues like accidents that result in death or injuries, an increase of toxic pollution and greenhouse gases, noise pollution, traffic jams, and mobility inequalities (Freund & Martin, 1993).

Autonomous vehicles (AVs) are the next generation of cars that are enabled by advanced sensors, navigation, and computer vision technologies that allow them to drive autonomously with the complete or partial assistance of humans (Mehedi Hasan et al., 2018). One of the goals of such vehicles is to increase their efficiency by optimizing its functioning and reducing the harmful effects. As technology advances, there are different levels of autonomy for these vehicles, depending on their autonomous capabilities and to what extent they need the assistance of a driver. Kandah et al., (2019) identify five levels of autonomy:

Level 1: Breaking and steering vehicle assistance provided by an Advanced Driver Assistance System (ADAS).
Level 2: The ADAS can take control of the vehicle steering and braking, under the control of the driver.
Level 3: Under certain conditions, an automated driving system (ADS) can take control of all driving tasks. ADS needs the driver to take such control.
Level 4: ADS can take control of tasks and monitor the environment in some circumstances. While there is no need for the driver to pay attention to such events.
Level 5: ADS can take control of the vehicle in all circumstances. No need for driver assistance; they are considered just passengers.

AVs use a wide range of sensors and actuators to collect data from inside and outside of the vehicle. This data is managed by Electronic Control Units (ECUs) that process complex operations. Other parts of the car like powertrain, chassis, body, telematics, infotainment, and vehicle-to-everything (V2X) communication are also controlled by their own ECUs. The communication between these different types of ECUs is crucial for the safety and performance of any AV because they form a complex network of data generation, data acquisition, and data processing (Mitra et al., 2019). Additionally, secure and tamper-resilient data aggregation are essential for AVs, especially for an ecosystem of connected vehicles within a shared state (Mitra et al., 2019).

Significant changes are coming in the automotive industry driven by society change itself, from an industrial to an information society. Connected and AVs are already causing changes in the automotive industry, and according to a recent report from multiple sources, the assumption that it will change the mobility industry is taken for this work. For instance, the work of Monios & Bergqvist (2020), emphasizes that AV will introduce a significant reduction in operation costs and acting at the same time as a driver for non-ownership business models. In addition to this, they state that there is a strong trend of decreasing the ownership of personal vehicles on the way to the utilization of Mobility as a Service (MaaS). This idea is also supported by the simulation created by Von Peinen et al. (2018), where they estimate a decline of almost thirty percent on the demand of personal car ownership until 2030. Additionally, according to that model, they predict that autonomous taxi services could make up to forty percent of the whole automotive industry by 2030.

In addition to this, sources like Bloomberg, Business Insider, and GlobalData say that the emissions of new licenses in Germany show an abrupt decline, especially from people between 17 and 25 years old (David Leggett, 2019; Jim, 2019; Nicola & Berhmann, 2018). This can be corroborated by the poor performance of European car sales in 2019, which decreased by 6 percent compared to the previous year. Furthermore, estimations of BMW state that one carsharing vehicle will substitute a minimum of three private cars (ING, 2018). Additionally, they stipulate that mobility services and autonomous vehicles will represent the third part of all the travels. Moreover, the report of ING, (2018) states that there is a reduction of 1 million in car sales through Europe per year and they estimate a decrease in sales of 13.5 million cars by 2035. The scenario seems similar in the United States, where the advisor group Berylls Strategy foresee that the sale of personally owned vehicles will drop by 12 percent until the year 2030 (Berylls Strategy Advisors, 2018). On the other hand, mobility services like Lyft or Uber and the pool of cars used for sharing mobility as a service experience an increase of 91 percent during 2017, and the compounded annual growth rate expected between 2018-2024 is 24 percent according to MarketWatch (Higgins, 2017). In this regards, it is interesting to study the interaction and imminent introduction of AVs to the mobility industry in the near future.

1.2. Mobility as a Service

With the increased penetration of connected and autonomous vehicles into the market, new opportunities and interest rises. Furthermore, changes in regulations and technology are expected to evolve in the future continuously, mainly by services enabled with autonomous driving (Von Peinen et al., 2018). Because of this, mobility services are going through relevant changes in their value creation and how they are being offered, empowered by the increased urbanization and connection of users and services providers.

The idea of MaaS is regularly treated as a one-stop, digital Intelligent Transportation System (ITS) platform that offers travel management regarding their distribution, acquisition, and journey creation (Wong et al., 2020). These types of services propose an on-demand use of vehicles which translate into a change from the fixed cost of buying a car to a variable cost depending on the amount of time and distance that the user needs.

These new modern mobility services are mainly enabled by advanced mobility technologies like the almost globally diffused smartphones, which can be seen as the utmost innovation in the transport industry in the last ten years. In addition to this, the internet of things, big data analytics, and AVs are working together to optimize transport networks, improve effective vehicle utilization while refining the usage of infrastructure and providing a better customer experience. Autonomous and connected vehicles are the essential elements that are pushing these changes by changing how the society interact with cars and its impact on the availability of public transport by reducing the relation between service capacity and costs (Wong et al., 2020). This means that AVs will increase transport capacity while reducing transport costs.

These new mobility services and technologies like AVs are complementing each other towards services and promoting a shift in paradigm regarding mobility. The private ownership of cars is not used as an asset nowadays and is going into a transition towards access on-demand services (Wong et al., 2020). These new mobility services are already operating in different countries around the world. For instance, in The Netherlands, there are three service providers (ConnectCar, Car2Go, and Greenwheels) that offer a pay-as-you-go carsharing scheme were users pay per distance or time of using the services. Furthermore, Nissan launches a car subscription service that allows drivers to use different cars by paying a monthly fee (Pietsch, 2020). This type of service is very similar to the ones that are already available from Audi, Mercedes-Benz, Lexus, and Volvo, where they offer cars as a monthly or yearly subscription which are more flexible methods than to lease a car.

With the rise of these new technologies, the introduction of new possibilities can enable innovative services and new business opportunities from the vast amount of data generated by these technologies. In this regard, the emergence of software and data management forms part of the core element in the value creation of such technologies (Skeete, 2018). AVs and their future services create a considerable challenge regarding how to manage data efficiently, security and privately and the vast possibilities and responsibilities that can emerge from this.

1.3. Autonomous Vehicles, Mobility as a Service and Blockchain

There are several challenges regarding AVs. Due to the novelty of the technology, there is no valuation criteria nor legislation available to guide the technology forwards. A collaboration between different governments and stakeholders is needed to push this innovation. In this regard, the government of The Netherlands actively supports AVs and has implemented the "Experimenteerwet zelfrijdende auto" law that gets rid of the legal barriers to work on this technology (Government of the Netherlands, 2016). Furthermore, the government recognizes the benefits that this innovation can bring in terms of environmental impact, efficiency, and safety. They also understand the importance of boosting job opportunities, growth, and competitive strength within the European Union.

These connectivity-based vehicles rely on networked software that is susceptible to issues like privacy and security of AVs ecosystems which can make them vulnerable to cyberattacks and hacks (Kim, 2018). They also rely on a synergistic data ecosystem and are considered a complex cyber-physical system that encloses an intelligent grid of dynamic and static information resources, which are crucial for the safety, security, and stability of such ecosystems (Mitra et al., 2019).

There are multiple issues regarding the trust, transparency, privacy, and security of AV ecosystems, from secure V2X communication, data breach, tight control, decision and diagnosis units, privacy, integrated embedded security, and more. Additionally, the vast majority of critical operations of AVs require a real-time response making latency a big concern for the secure design of an AV ecosystem. In regards to data privacy, security, and trust, technologies like Blockchain (BC) can be useful due to its tamper-resilient and verifiable record of transactions, which enables a provenance of data, the validity of data and immutability of data (Mitra et al., 2019).

BC is a distributed technology that includes a hash function, cryptography with digital signatures, and time sequence (Yang et al., 2019). Additionally, BC is composed of two types of elements. First, transactions: Which are the activities created by the participants in the system. Second, blocks: Which are the transactions recorded to make sure they are not tampered with and stay in the correct arrangement (Mehedi Hasan et al., 2018). This distributed ledger technology (DLT) poses many benefits, especially in modern data privacy and real-time automation with the use of smart-contracts. One of the main advantages of technologies like BC is their ability to provide a safe and tamper-resilient within a shared state, especially useful for AVs ecosystems and grids (Mitra et al., 2019). In this sense it is interesting to use these properties to solve the needs for trust, secure and tamper-resilient data aggregation of AVs by using BC technologies in the MaaS industry.

1.4. Knowledge gap

To identify the knowledge gap explored in this master thesis research an academic literature review was conducted. This was achieved in two parts: First, a literature review on studies that consider changes in the Mobility as a Service industry related to the introduction of Autonomous Vehicles is presented in Appendix A. The findings in this literature review revealed the foreseeable introduction of AVs to the mobility and automotive industries and the possible upcoming technology challenges. In this regard, issues like privacy, security, and trust where the most frequent topics of research and discussion among the articles founded.

The second literature review presented in Appendix B was done by searching studies that consider the use of BC technologies in the mobility and automotive industries, especially in its application to AVs and MaaS. This is done by reviewing their discussions or research findings for the main three topics found in the first literature review and how BC could help to solve the main issues of privacy, security, and trust.

From these literature reviews is possible to see the lack of research and models for a BC-based MaaS system with the adoption of AVs. In this regard, the most elemental systems, components, requirements, and configurations were missing in the literature. These findings where the motivational triggers to develop the research proposed in this master thesis. All of this creates a problem for organizations where the lack of knowledge and involvement with the combinations of these technologies introduce considerable uncertainty for the future of organizations, institutions, and its users. The main issues found in the literature are about trust, privacy and security. In this regards it is the interest of the researcher to explore the capabilities of BC regarding these issues and what it could mean to the design of a BC-based MaaS system with the adoption of AVs.

Since there are not concepts or designs of a BC-based MaaS system that uses AVs this research could be useful to start developing such concepts. In this sense, by exploring how might a BC-based MaaS system that uses AVs would look like could be useful for researchers and future mobility or automotive organizations that would develop or implement such a system. By doing so, this research could provide a first approach to the requirements, BC architecture, business processes and enterprise architecture of a BC-based MaaS system that uses AVs.

1.5. Scope

There are mainly three leading technologies interacting; their interaction and possibilities are vast. Due to this and to not lose focus, this research needs to concentrate in particular domains. The term autonomous vehicle is usually the most recurrent one in the literature to refer to autonomous transportation means. However, the word vehicle has a broad meaning, it could be something to transport goods or people, it can also vary in its form. A vehicle could be any means of transportation like motor vehicles, railed vehicles, watercraft, aircraft, among others. These broad types of vehicles would make this work too extensive hence the decision to limit its scope to just motor vehicles and especially cars. The choice for this is because most of the currently available MaaS and carsharing services are focused on personal cars. Hence when in this work using the term AV, in reality, it refers specifically to autonomous cars that are used on roads, have four wheels, and offer capacity from one to eight passengers.

There are different levels of autonomous cars. For this work, a future scenario is considered were AVs will operate on Level 5 of autonomy. This means that there will be no need for the users of the vehicle to drive the vehicle or even have a driver's license. Moreover, one of the requirements for future AVs is the implementation of the fifth-generation networks (5G). In this regard, 5G can introduce new capabilities like lower latency, edgeless connectivity, increased capacity, and fundamental changes of connection paradigms (Zheng et al., 2017). Currently, there is no experience in this technology; it can create new challenges that could affect the safety and performance of AVs. The usage and overuse of a 5G network is not being tested yet for AVs. Issues like bandwidth, security, interruption, jitter, and ping need for more research and especially their repercussion on the latency in AV ecosystems. Due to this, the assumption that these technologies will be fully implanted in the future is taken for this work, being such important aspect of an AV ecosystem, it is relevant to take these technologies as an already established component.

Carsharing is becoming a feasible alternative to own a car with different ownership models like peer-to-peer (P2P) or even fleet managed, they also can be found on different operational models like roaming, return-to-base or one-way. They will mainly operate in urban environments, but an increase is also expected in suburban settings (Shaheen & Cohen, 2012). The major factors that seem to influence this are demographic changes, a decline in the emission of new driver licenses, and a downward trend on drivers by millennials (McDonald, 2015). In addition to this, nowadays, the car has lost its social status symbol, something that is reflected in the drop in sales previously mentioned. The future growth on the mobility market has also caught the attention of researchers: an increase of articles on the topic is observable (Utriainen & Pöllänen, 2018).

It is also relevant to consider the environment for the scope of this research. In this sense an urban environment is considered over a suburban one. Smart cities are the frontier environment to tackle urban issues while progressing towards a better quality of life in the cities of the future (C. Zheng et al., 2020). This is particularly true in an information society, in with the economy is mainly driven by information and knowledge, which focuses on information resources to encourage urban developments (M. Guo et al., 2016). With this, information and communication technologies (ICT) are becoming a significant element when it comes to solving issues in cities. It is possible to now see different initiatives from governments all over the world to include smart city solutions to tackle the challenges for the cities of the future.

Nevertheless, there is no consensus on a clear definition of what is a smart city. In addition to this, the concept of the smart city extends along with other similar concepts like digital city, intelligent city, knowledge city, and sustainable city (Nam & Pardo, 2014). While the idea of a smart city is not new, it has evolved from a digital city to an intelligent city, and now they are seen as smart cities (Mora et al., 2019).
Although the concept is not yet evident in the literature, there is a commonly use a conceptual framework that analyzes smart cities in six different dimensions (C. Zheng et al., 2020):

- ***Smart Mobility***
- *Smart Environment*
- *Smart People*
- *Smart Living*
- *Smart Governance*
- *Smart Economy*

In this regard, a smart city "is a system of systems, involving the symbiotic linkage among people, institution, technology, organization, built environment, and physical infrastructure (Chourabi et al., 2012; Nam and Pardo, 2011a)" (C. Zheng et al., 2020, p. 2). In addition to this, European Parliament proposes a more broad definition: "a city seeking to address public issues via ICT-based solutions on the basis of a multi-stakeholder, municipally based partnership" (Manville et al., 2014, p. 9). Considering the elements and dimensions previously mentioned, this work is focused on the Smart Mobility dimension in a smart city.

It is relevant for this work to specify its scope and design space for a future MaaS concept enabled by BC with the use of AVs. This is done by only selecting AVs in the form of driverless cars. Furthermore, they will be operated by a carsharing MaaS concept in the Smart Mobility environment of a smart city. For this, the setting of an urban environment is selected, mainly due to the current support that the government is developing for AVs. Additionally, an urban environment is selected as a limited boundary to develop the proposed concept in a specific delimited area.

1.6. Problem definition

Mobility as a service are already operating in different parts of the world acting as a replacement for car ownership and offer the user a more sustainable way of transportation, cost reductions, and a release of the many responsibilities that comes from owning a car. Furthermore, users can also benefit from things like no parking costs, one-way trips like going to the airport, insurance, road assistance, cleaning the vehicle, taxes for owning a car, among others. In such a service, people are expected to experience numerous changes, tasks, opportunities, and uncertainties when it comes to operating within this new MaaS environment.

MaaS is continuously growing, and according to the information provided, it will continue to grow in the upcoming years. Nevertheless, there are numerous uncertainties on how they will operate with the introduction of AVs and the current issues or difficulties that this automatization technology is experiencing. The most recurrent challenges in the literature about these technologies are security, privacy, and trust (Appendix A). On the other hand, it is also possible to find articles that describe the capabilities of DLT and ways of solving those issues for MaaS and AVs with the implementation of technologies like BC (Appendix B).

The idea of using BC as a possible solution for this research comes from the capabilities of DLT. AVs are a new technology that still needs to capture trust from its users (Mehedi Hasan et al., 2018). Moreover, these AVs rely on a synergic data ecosystem for data generation, processing, and acquisition (Mitra et al., 2019). In this regard, AVs do not possess the required capabilities to process, store and verify information forcing them to rely on third parties which can fail to result in the collapse of the whole system and creating trust issues (Mehedi Hasan et al., 2018). Nevertheless, a decentralized approach could eliminate a single point of failure increasing the resilience of the ecosystem. Besides, BC could also increase the reliability of the user's data by increasing security and privacy (Mehedi Hasan et al., 2018).

The main issues of security, privacy, and trust are also relevant market and technology drivers in the mobility industry (Romanski & Daim, 2019). In this regard, BC can be used to set a decentralized, secure, and trusted autonomous ITS ecosystem but there is a critical need for creating an ecosystem architecture that enables a free flow of data, assets, and money withing an ITS ecosystem (Yuan & Wang, 2016). Moreover, the existing models that use BC technologies in MaaS environments are variated and do not provide a complete overview of the whole ecosystem (Karinsalo & Halunen, 2018). This is confirmed by the literature reviews presented in Appendix A and Appendix B were no scientific articles were found that combine these three technologies to take advantage of their properties or explain how their interaction could work in the future.

1.6.1. Scientific contribution

By exploring how a BC-based MaaS system with the adoption of AVs could look like some scientific contributions could be made by this research. In this regard, the goal of this research is to provide a set of requirements, BC architecture, business processes and reference architecture for a BC-based MaaS system with the adoption of AVs. These design artefacts could be useful for future researchers or industries that aim to further develop or implement MaaS systems with the adoption of AVs

1.6.2. Societal contributions

This research could also deliver contributions to society, specially to the mobility and automotive industries. By proposing a set requirements, BC architecture, business processes and reference architecture for a BC-based MaaS system with the adoption of AVs it could have numerous improvements to society. Furthermore, the delivery of the proposed artefacts could lead to faster and easier adoption of these technologies which can result in a direct impact on introduction of AVs to the users. By doing so, it could also introduce all the benefits of AVs like reduce emissions, accidents, traffic, overhead costs. Moreover, it could also help to the transport industry by enhancing transport networks, infrastructure utilization while reducing costs and improving user experience.

There are lots of opportunities from the capabilities of these different technologies and their interactions. Being a complex socio-technical issue there are multiple technical components and stakeholders in place. This could introduce errors and widely increase the number of elements interacting in this system which can be too big to study due to time and working resources for this research. Because of this, the research of this work is limited to a specific case where it looks into the use of AV within the MaaS system based on BC at an abstract level. Furthermore, this research studies the interaction between AVs, users, data operator, and insurance companies within a BC-based MaaS system with the adoption of AVs. A graphic representation of this particular case of study is presented in Figure 1, where it is possible to see the main focus of this problem and system of interest.

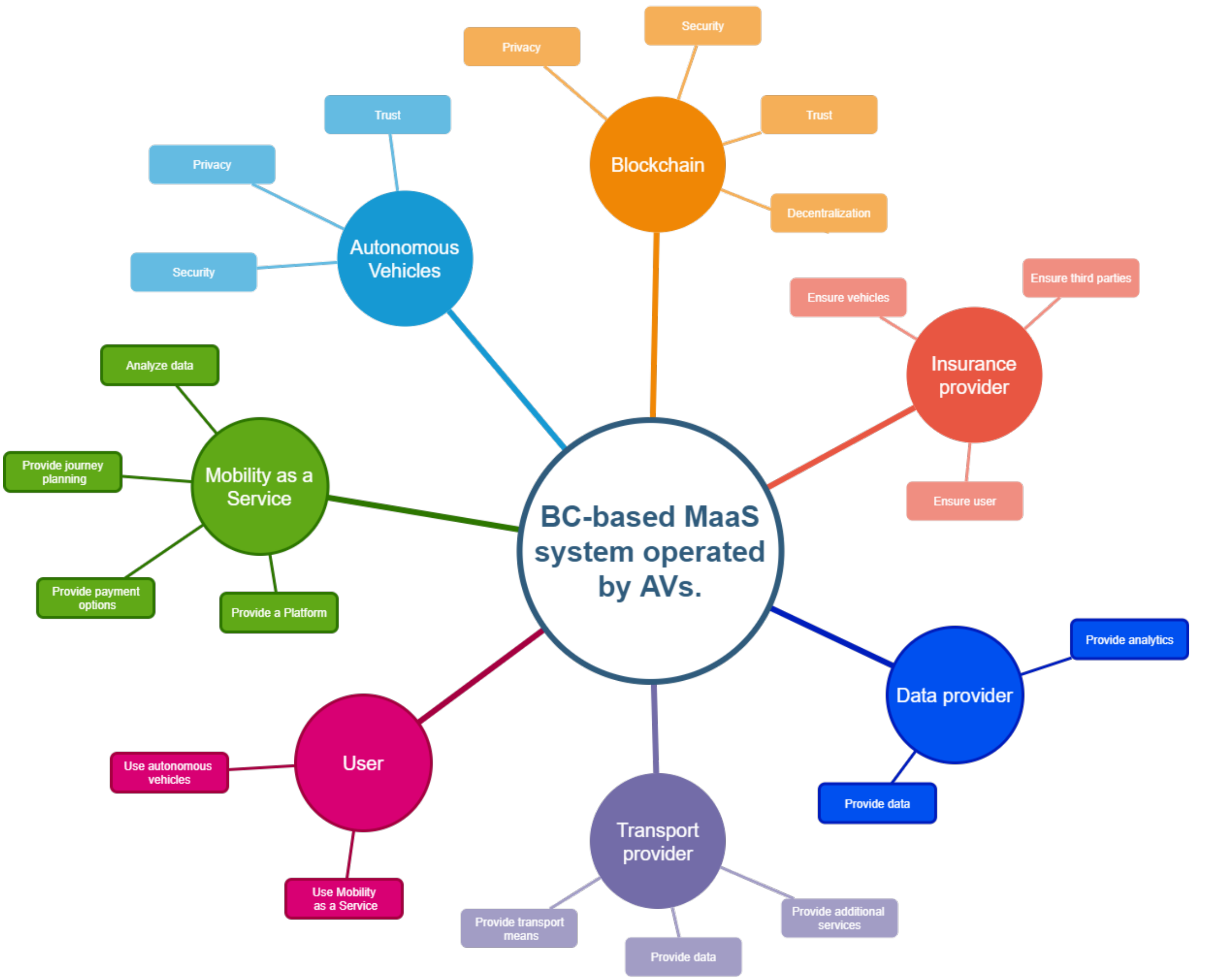

Figure 1: System of interest

2. Research design

To develop this work, a research design is required. In this chapter, the research objective is presented in section 2.1. After this, the general research proposition is explained in section 2.2, founded on the problem definition and research objective. Following this, the main and sub-questions are introduced with the different methods to answer these questions in the same subchapter. Furthermore, the possible contributions of this work are proposed in section 2.3. The socio-technical relevance of this work is mentioned in section 2.4. Finally, the possible limitations of this research approach are described in chapter 2.5.

2.1. Research Objective and research question

Taking the problem definition into account and the identified knowledge gap in the area of Intelligent Transportation Systems and Autonomous Vehicles, the objective of this research is focused to build and evaluate an artefact that aims to the following objective:

Explore what a Blockchain-based Mobility-as-a-Service concept design with the adoption of Autonomous Vehicles would look like, their most elemental systems, requirements, and possible configurations.

According to the relevance and future possibilities of BC, MaaS, and AVs, this research will provide a first insight into how the design of such a system would look like. Within an IS research project it is possible to explore the initial understanding, where people, organizations, and technologies are entangled to offer a future design for MaaS. Following this, the main research question that will be answered is:

How might a Blockchain-based Mobility-as-a-Service system with the adoption of Autonomous Vehicles concept design look?

2.2. Research approach and methods

For this research project, a Design Science Research (DSR) approach is taken to organize the overall plan of this research. This research follows the phases and DSR methodology proposed by Johannesson & Perjons, (2014) and can help to structure this work, safeguard the quality of the results, and present it in a logical and manageable way. Furthermore, this method is formed by four major components; Logically related activities with respective input and output, guidelines for performing such activities as well as for choosing strategies and methods, finally it also provides guidelines to relate the current knowledge base for this research. Furthermore, a systems engineering perspective is also taken due to the high complexity and socio-technical characteristics of the previously mentioned problem definition and research objective. DSR is a combination of two different paradigms; behavioral science and design science (Hevner et al., 2004).

Behavioral science comes from natural science, and its objective is to justify theories to clarify the human and organizational phenomena in regards to its design, analysis, and implementation of IS (Hevner et al., 2004). On the other hand, the design science paradigm is a problem-solving paradigm. This paradigm has the objective of developing artefacts that can help to design, analyses, implement, and manage solutions for IS (Denning, 1997). Moreover, the creation of these artefacts are based on kernel theories that provide help to the researchers in their search for solving problems (Markus et al., 2008). An IT artefact can be expressed in the form of information constructs, methods, models, and instantiations. These IT artefacts can be studied by behavioral-science if they are applied to the organizational context and in design science, they are the focus to create and evaluate IT artefacts that aim to solve organizational issues (Hevner et al., 2004).

To systematically analyze the problem mentioned above a complex socio-technical system perspective is taken. To design in a complex socio-technical system, the study of other systems that form part of the first system, often called sub-systems, is conducted. Furthermore, a TIP (Technology, Institutional, and Process) design is taken into account. This TIP design means that technical and institutional components are studied to produce functional processes (Bots & Els Van Daalen, 2012). In this regard, a system description is presented by using the literature review and desk study to realize a technical analysis, an institutional analysis and a stakeholder analysis.

For the literature review of this research, studies where searched by using specific keywords in reference databases like Scopus, Web of Science, and Google Scholar focusing on English journals. The literature search is conducted in two steps. First core concepts like "Autonomous Vehicles", "Blockchain" and "Mobility as a Service" to have a clear definition of what these terms mean and what is state of the art regarding their research. The second step was to use a combination of keywords like "Autonomous Vehicles AND Blockchain", "Mobility as a Service AND Blockchain", "Mobility as a Service AND Autonomous Vehicles". From these search terms, a considerable number of articles appear, but when a search is done for Blockchain-enabled Mobility as a Service with the utilization of Autonomous vehicles, no scientific articles where found.

The artefacts proposed for this work are design choices to consider for the design of a BC-enabled MaaS with the adoption of AVs. In this regard, a DSR approach is used to guide the design such artefacts and design choices regarding MaaS, AVs, and BC technologies. Being the proposed design of an information system, IS and DSR provides a good fit for design, develop, demonstrate, and evaluate such artefact (Johannesson & Perjons, 2014). Furthermore, this methodology proposes five distinctive phases; *Explicate Problem, Define Requirements, Design and Develop Artefact, Demonstrate Artefact, Evaluate Artefact*. Given these phases, different sub-questions are proposed to develop these phases.

2.2.1. Sub-questions

To achieve the main research question, several sub-questions must be explored:

I. *How would a MaaS system based on AVs look?*
   a. *What does a technical sub-system look like?*
   b. *What does the institutional sub-system look like?*
   c. *Which relevant stakeholders could form part of a MaaS system based on AVs?*

This first sub-question *I* is proposed to address the Explicate Problem phase of the DSR approach. For this research and taking into consideration the TIP design approach, a minor change in the name of this phase is taken. Due to the fundamental elements in this research; people, organization, and technology, this work is conducted with an Information Systems (IS) research approach. Customer trust, behavior, and decisions do not permit a quantitative analytical study (Von Peinen et al., 2018), and the deficiency of standardized technologies and tools within the industry only increases the complexity of this technology and its applications (Accenture, 2018). Furthermore, the integration of such systems will require a socio-technical system design due to the interaction of people and technology. The name of this phase is changed to System Description, and the output from this is a System Analysis. To answer the question *I,* a series of sub-questions are proposed in *a, b, c*. These questions aim to provide a descriptive knowledge and characteristic of the environment of the system of interest. In question *a*, the technical system is analyzed to get an overview of the technical sub-system and further define the system. To answers question *b*, the institutional subsystem is studied to have an overview of rules, regulations, norms that might influence the system to understand its environment. Lastly, question *c* is answered by an overview of the most relevant stakeholders, their roles, and their interaction with the system. By doing so, it is possible to identify the functionalities, regulations and roles of the technical, institutional and stakeholder sub-systems.

II. *What are the requirements needed for a MaaS system based on AVs?*

The goal of this question is to address the second phase of the DSR approach. For this, sub-question number *II* is proposed for eliciting, analyzing, categorizing, and prioritizing the requirements for this system. Moreover, due to the complex socio-technical perspective, the sub-question I and their subsystems need to be aligned. To do this alignment, requirements are elicited to gain knowledge of the technical, institutional, and stakeholders requirements. This is achieved by identifying the technical, institutional and stakeholders needs that need to be satisfied by the system. In addition to this, a user case scenario is used to further clarify and illustrate a trip scenario from the user perspective. By doing so, a set of requirements for a MaaS system based on AVs is proposed. These set of requirements are used in the next phase of this research as inputs that need to be fulfilled by the proposed artefacts.

III. *How does a BC-enabled MaaS with the adoption of AVs system architecture look?*
   a. *What are the design options to consider?*
   b. *How does the architecture fit the requirements?*

This third phase is about how to design and develop the proposed system. This is achieved by analyzing the possible alternatives of BC types and architectures that can fit into this design by fulfilling the requirements of the previous phase. To develop the sub-activities needed for this phase question *a* is formulated to generate ideas that can be used as a base for the design of the artefact. To guide this idea generation the work of Tasca et al., (2017) is used to identify the components and sub-components of a BC architecture while selecting the ones that best satisfy the requirements. Furthermore, question b is answered by assessing and selecting these ideas of the BC design alternatives, then building a sketch on that represent the BC architecture for the system. Finally, provide the design justifications and rationale to prepare for the following phase to demonstrate how does the system would look like.

IV. *Which business processes and reference architecture could support the design of the BC-enabled MaaS concept system with the adoption of AVs?*

Question IV is proposed to develop the fourth phase of this design to demonstrate how the system would look like by demonstrating the use of the proposed artefacts in a specific case scenario. This is achieved by demonstrating how the business processes support the main functionalities of the system. Moreover, with the intention to illustrate these business processes a Business Process Model and Notation (BPMN) is used, which is a modeling tool for demonstrating the business process with a standardized language. In addition to this, this phase illustrates the design of a reference architecture, that is visually represented in an ArchiMate model, to have an idea of the system structure needed for support the main business processes of the proposed system.

V. *How to evaluate the BC-enabled MaaS concept system with the adoption of AVs?*
   a. *How to evaluate the process of this research?*
   b. *How to evaluate the design requirements and its reflection on the artefacts?*
   c. *How to evaluate the objective proposed in this research?*

This final phase of this research is created to evaluate the proposed artefacts in this research with interviews. Interviews are a method for collecting information about experts opinions; they are communication meetings controlled by the researcher where questions are asked to the interviewed. In this regard, interviews are adequate for collecting complex and sensitive information (Johannesson & Perjons, 2014). There are different types of interviews; for this work, semi-structured interviews are used. This type of interview can provide the respondent with more freedom to answer questions and are more suitable for complex problems like the one proposed in this work. This is conducted via a semi-structured interview with a group of experts to evaluate the research process by answering sub-question *a*. Furthermore, question *b* is created to assess the fulfillment of the requirements in the artefacts. Finally, question *c* has the objective to assess the ability of the artefacts to explore a BC-enable MaaS concept system with the adoption of AVs look like. With the objective of answering these questions an evaluation plan is proposed followed by the selection of a relevant group of experts. Moreover, their comments and feedback are considered and corrections are presented in this final phase.

2.2.2. Research flow

To facilitate the readers understanding of the flow of these phases, an illustration is presented in Figure 2. With this diagram, it is possible to see in a structured way the needed research activity, different phases, methods, and knowledge for each phase of this research. The green rectangles represent the needed step for each chapter, within this, purple diamonds represent what question is being answered and what will be the outcome of that phase. Besides, the yellow squares represent what methodology is proposed to answer that question. Furthermore, at the bottom of the figure, the knowledge base or kernel that are the primary sources of theories to help inform the artefact design.

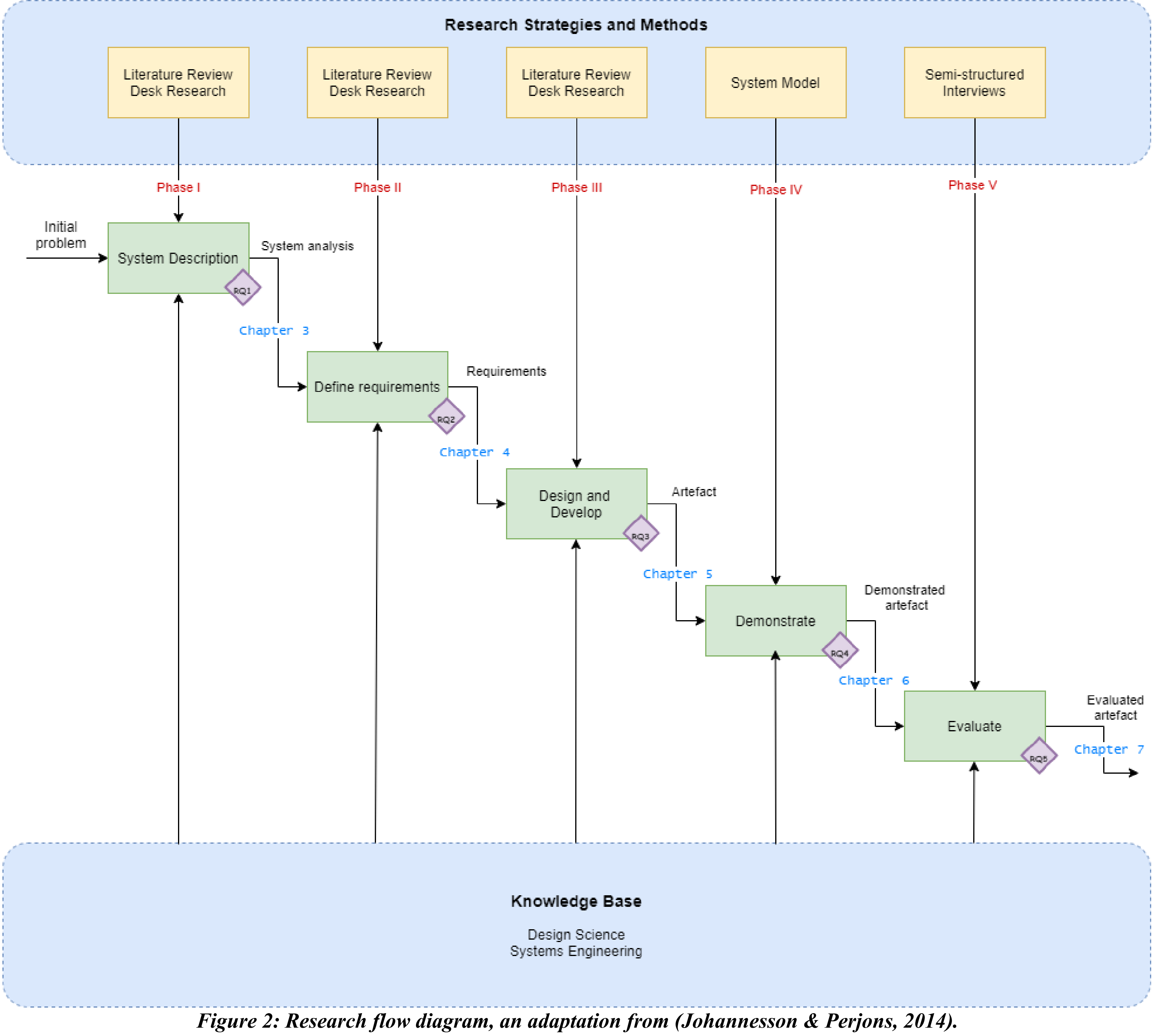

Figure 2: Research flow diagram, an adaptation from (Johannesson & Perjons, 2014).

3. System description

In this chapter the first question is answered; *I. How would a MaaS system based on AVs look?* This is achieved with desk research and a literature review that is presented in Appendix A. To answer this question a system description is conducted where the system of interest is decomposed into three sub-systems. These are the technical, institutional, and stakeholders' sub-systems. Generally, IS is not just their technical part but also about their user's trust, behavior, rules, and regulations. Because of this, a socio-technical point of view is taken to analyze these sub-systems. The technical analysis is conducted in 3.1. Following the institutional overview that is presented in 3.2. In section 3.3 the stakeholder analysis is presented were a representation of how the ecosystem of these actors would look like. Finally, the conclusions from this chapter are expressed in 3.4.

3.1. Technical analysis

This technical analysis is focused on current technical systems, in this case, MaaS. To do this and design the technical artefacts certain characteristics of the system are needed. Furthermore, these characteristics could be functional or non-functional and represent the technologies and systems that are identified in this research. To do this it is necessary to answer sub-question I.a; *What does a technical sub-system look like?*

3.1.1. Mobility as a Service

In general, MaaS is a user-centric, personalized, and on-demand intermodal or multimodal transport solution to optimize transport mobility. Moreover, they are offered in a single digital platform in an intelligent way with the support of ICT infrastructure for the correct functioning of a MaaS ecosystem (Kamargianni & Matyas, 2017).

In this work, MaaS is the technical artefact to optimize the supply and demand for transport in urban or intercity environments. This optimization is further supported by ICT which encourages the development of a more effective transport network, vehicle, and infrastructure utilization while providing uninterrupted journeys. Besides, MaaS has the capacity to increase value in society by providing additional data and effective use of transport management tools (Kamargianni & Matyas, 2017). Furthermore, as a new business model that is being introduced to cities, it can provide an additional income from taxes for the local authorities. By the same token, it can also contribute to a reduction of car ownership thus contributing to the environment and sustainable mobility for future generations.

To understand how this technical artefact works and answer question I.a a definition is required. While there are multiple definitions in the literature about what a MaaS is for this work the definition of Kamargianni & Matyas (2017) is used. They state that a MaaS is defined as follow:

> *"Mobility as a Service is a user-centric, intelligent mobility distribution model in which all mobility service providers offerings are aggregated by a sole mobility provider, the MaaS provider, and supplied to users through a single digital platform."* (Kamargianni & Matyas, 2017, p. 4)

Current transport services are varied and offer different planning tools, payments methods, and tickets options for its users. This creates uncertainties for the user, lack of intermodal trips, and decrease the option of sustainable travel behavior (Kamargianni & Matyas, 2017).

MaaS uses payment models were the user can use pay as you go or subscription modes that can vary and adjust to the needs of the user. Furthermore, they enable the user to create their own personalized journeys, hence the user can opt for the booking and payment mechanism that better adapt its needs in only one service (Jittrapirom et al., 2017). This is personalization is a core characteristic of MaaS, very similar to subscription services like telecommunication companies. Nowadays is possible to see an example of this being offered by car companies like Volvo, BMW, Audi, Nissan among others where the user pays a monthly fee or pay as you go model.

Transport on demand can offer the ability to provide transport solutions to travelers in their city and also around the world, which is an element that some companies already offer to their clients via on-demand and carsharing services. Furthermore, transport on demand can be offered directly to consumers in business-to-customers (B2C), business-to-business (B2B), or a combination of both services (Kamargianni & Matyas, 2017).

There is a change of ownership models in the transport system that is being encouraged by the combination of different mobility services being offered. In addition to this, custom made mobility solutions propose a threat to private ownership of cars (Jittrapirom et al., 2017) this could be further increased with the introduction of AVs.

This research is focused on a carsharing scenario of AVs, but it forms part of the shared mobility. Carsharing is considered when users rent a vehicle for a determinate period of time for sporadic use. The owner of the shared vehicle could be a company, an individual, or a collective of owners. These carsharing services are offered via different models like; roundtrip, fractional, peer-to-peer, or one-way.

Another relevant element is the MaaS provider that acts as the intermediary between the transport provider, in this case, the owner of the AV, and the final user. This provider uses the data from the transport operator, buys its capacity to offer it to the user (Kamargianni & Matyas, 2017). Additionally, a support element for the interaction between the MaaS provider and transport provider is a robust ICT infrastructure and good internet speed connectivity. This is because the need of the user to get access to real-time information for trip planning purposes (Kamargianni & Matyas, 2017). There are more actors involved in a MaaS ecosystem but these are analyzed in section 3.3

3.1.2. Core characteristics

MaaS possess some interesting characteristic that defines how this subsystem would look like and are useful to identify to elicit technical requirements later. These characteristics are also relevant to identify what elements form part of a MaaS concept and its implication in such a concept. To look into these core characteristics the work of Jittrapirom et al., (2017) is studied. They propose 9 core characteristics that are based on a literature review of 12 MaaS schemes from different authors. These characteristics are presented in *Table 1* with some adaptations to align with the objective of this research.

Characteristics	Description
Integration of transport modes	An objective of MaaS is to inspire the use of multi-modal transportation by letting the user choose their preferred transportation means. For this work, the preferred transport mode is only carsharing. Nevertheless, the user can take advantage of the connection to long-distance travel like buses, trains, flights, bikes, or ferries.
Tariff option	Generally, there are two types of tariffs in MaaS platforms; pay as you go or a subscription model. The first charges the user depending on their actual use of the service. The second model offers a bundled service with a certain amount of km/minutes/points at the disposition of the user.
One platform	MaaS systems use a digital platform where users have the ability to access the key service for their trips like planning, booking, real-time information, payment, and ticketing. Other services can be included but they are out of the scope of this research.
Multiple actors	MaaS ecosystem is characterized by the interaction of multiple actors like users, transport providers, platform owners among others. These are further analyzed in chapter 3.3.

Use of technologies	Technologies are a key enabler for MaaS with elements like personal computers, smartphones, internet networks, GPS, payment and ticketing systems, database management systems, and Internet of Things (IoT) devices.
Demand orientation	MaaS is a user-centric transport solution that aims to offer transport solutions that best serve the customer's needs via planning and demand-responsive services.
Registration requirement	The user needs an account to access the offered services. This also provides the user with the ability to personalize his account and the services that he can access.
Personalization	With a personalized account the platform can ensure that the user requirements and expectations are more efficient and effectively meet to adapt to different customers. Furthermore, they can also offer the user recommendations, preferences, past behavior, and tailor-made solutions based on their profile.
Customization	With a customized account the user can modify the offered services to best suit their preferences. They can create chained trips or adapt their mobility package depending on their needs. This would raise the appeal, attractiveness, and loyalty of the MaaS system.

Table 1: Core characteristics of MaaS system, adapted from (Jittrapirom et al., 2017)

3.1.3. Key functionalities

After analyzing the core characteristic of a MaaS system some key functionalities that are needed to support these core characteristics. Furthermore, these key functionalities will correlate with a variety of transactions that are needed to support such a system. These take the form of tools and services that the users need to take a trip; Planning, Booking, Access to real-time information, Payment, and Ticketing (Kamargianni & Matyas, 2017). Furthermore, it is also relevant to add the ability to identify the user which is needed to sign digital transactions, offer customization, register, and validate the users. A description of these key functionalities is presented next.

User identification

User identification is needed to support characteristics like registration, personalization, customization among others. This could also enable the user to access the other key services mentioned in this chapter. Furthermore, MaaS systems require a single identity to travel and opt for payment methods (Li & Voege, 2017). In MaaS systems this identity is linked to the user data which at the same time is present in all the key services that are described below.

Planning

A journey planner consists of a tool that is used to optimized traveling between different locations. They could use filtering criteria like type of road, fastest route, avoid tolls, cheapest among others. A good example of a trip planning is the Google Maps application, were the user can select the destination with a specific timeframe, mode of transportation, routes, connections among others. This application will display the available transport choices for the user and order them by time. In this sense the MaaS provider as already available options of journey planner that it can offer in its platform. Additionally, MaaS provider as the possibility to further increase value to their service by providing location and demand data from its users (Kamargianni & Matyas, 2017).

Booking

The booking gives the ability to the user to reserve a particular vehicle or trip. This would usually refer to certain payment conditions, availability and geographical characteristics of the transport mean.

Access to real-time information

Real-time information is a common future of trip planning applications, this can be seen in the example of Google Maps mentioned before. Furthermore, the MaaS ecosystem is dynamic, this means that the system can adjust for disruption in the system like network failures, high capacity occupancy, etc. Also, the MaaS operator should be able to transfer customer requests and the capacity of transport operators in real-time. For this, an ICT infrastructure that supports high-speed connectivity and extensive geographical availability of the connection is a fundamental aspect to enable MaaS (Kamargianni & Matyas, 2017).

Payment

As mentioned before, payment can be done for different subscription options. Furthermore, current technologies are widely available to facilitate payment options like smart contracts, credit cards, online payment services that are linked to a smartphone among others. In this sense, the MaaS provider could externalize this service with other companies to enable the user to pay for its purchases (Kamargianni & Matyas, 2017).

Ticketing

In current MaaS platforms ticketing takes the form of e-ticketing that are stored in a digital wallet within a smartphone. For this, there are several technologies available but considering that MaaS is offered via smartphones these digital wallets are the ideal solution (Kamargianni & Matyas, 2017).

These key functionalities are the basics that are needed to develop a MaaS system. Moreover, these will take the form of transactions that are needed to be performed by the system. The introduction of BC and AVs could create some differences from current models. A relevant analysis of their requirements and design implication is studied in the following chapters.

3.2. Institutional analysis

The objective of the institutional analysis is to identify an overview of the regulations that could affect a BC-enabled MaaS system with the use of AVs. This research focuses on a futuristic scenario were the assumption that technologies like fully AVs, 5G, and other supporting technologies are operational and they can work with the rules and regulation of such a futuristic scenario. Because of this, is not relevant for this work to realize a deep analysis of current system characteristics and the interaction of actors from an institutional perspective. Nevertheless, MaaS systems introduce new expectations regarding trust, transparency, and reliability, which are dependent on the social network and data to enable them (Cottrill, 2020). This section aims to answers question I.b; a. *What does the institutional sub-system look like?*

3.2.1. GDPR

MaaS systems rely on personal data and regulations like General Data Protection Regulation (GDPR) can possibly impact the implementation of MaaS systems. In this regard, issues like Privacy by Design, Consent, and Protection must be considered to work in a European environment (Cottrill, 2020) such as the one of this research. Moreover, GDPR states that this new law applies to *"the processing of personal data in the context of the activities of an establishment of a controller or a processor in the Union, regardless of whether the processing takes place in the Union or not"* (GDPR, 2016, article 5)

A relevant element in this regulation is the protection of personal data, which is defined in GDPR, as *"... any information relating to an identified or identifiable natural person ('data subject'); an identifiable natural person is one who can be identified, directly or indirectly, in particular by reference to an identifier such as a name, an identification number, location data, an online identifier or to one or more factors specific to the physical, physiological, genetic, mental, economic, cultural or social identity of that natural person"* (GDPR, 2016, Article 4)

Elements like location data and online identifiers are relevant for a MaaS ecosystem and form part of the core characteristics that are needed to be fulfilled by the key functionalities. Furthermore, MaaS systems need to process user data to enable these core characteristics which need to be aligned with the GDPR regulations. Complying with these regulations is essential for the development of a MaaS system, for this a summary of the most representable articles that could affect this design is presented in *Table 2*.

Law	Article	Description
Privacy by Design	***Articles 5, 25***	Privacy by design means that data protection should be included in the design phase of the system. Furthermore, data needs to be stored in a way that is protected against unauthorized or unlawful processing, damage, or loss. It also demands to *"implement appropriate technical and organizational measures … to protect the rights of data subjects"*.
Data minimization and purpose limitation	***Article 5***	GDPR encloses principles for processing personal data. Data Minimization is one of these principles and means that only if necessary, data can be collected, and it needs to be deleted if is no longer used. Another principle is Purpose Limitation, this means data can only be collected and processed for a specific, explicit, and legitimate purpose.
Breach notification	***Article 34***	If the personal data is breached and is *"likely to result in a risk for the rights and freedoms of individuals"* a notification must be sent to the affected users.
Data protection Officers (DPOs)	***Articles 37, 38, 39***	DPOs are in charge of controlling GDPR compliance and collaborate in data impact assessments. These are obligatory if in the system are *"regular and systematic monitoring of data subjects on a large scale"*.
Obligation to conduct data protection impact assessments	***Article 35***	When is desired to process data at a large scale in a new way, an impact assessment must be conducted when this data is processed for *"a systematic and extensive evaluation of personal aspects relating to natural persons which is based on automated processing, … that significantly affect the natural person."*
Right of Access	***Article 15***	This is *"the right to obtain from the controller confirmation as to whether … personal data concerning him or her are being processed, and … access to the personal data."* This means that the MaaS user consent policy should inform the user if their data will be processed and grant access to it.
Right to erasure ('right to be forgotten')	***Article 17***	This gives the right to the user to delete certain data to deny others to access it if desired.
Affirmative Consent	***Article 7***	This means that the MaaS operator should inform explicitly to their users what data is being obtained and how it is being processed. Furthermore, consent to access this data must be given by the user in addition to a withdraw from it.
Use of Cookies	***Article 5***	Cookies are used to analyze the success of website advertising and design identifying the user engagement in online transactions. This can be used to *"create profiles of the natural persons and identify them"*, GDPR establishes that the user must explicitly consent their use.

Table 2: GDPR articles that affect a MaaS system.

3.2.2. Institutional assumptions

Although some new laws permit the testing of AV in certain conditions like the “Experimenteerwet zelfrijdende auto’s” law in The Netherlands, there are no current legislations that regulate the use of AVs in Europe (European Parliament, 2018). For the proposed BC-based MaaS system with the adoption of AVs, it is fundamental that these types of vehicles can circulate in every road. Because of this, it is needed to assume that laws and regulations in the future will permit the use of fully AVs. Moreover, these vehicles will need to be operated without the assistance of a driver or constant monitoring. In this regard, it is taken the assumption that regulations about liabilities and insurances regarding accidents where AVs are involved are up-to date.

Key supporting technology like 5G networks, infrastructure, and institutional placement, and actors should also be ready and enabled for their use. In addition to this, the assumption that the user and institutions accept this kind of technology is also taken. Overall the need for policy frameworks and recommendations for passenger rights, privacy, safety, security, social inclusion, sustainable development, and fair competition of the market (Kamargianni & Matyas, 2017) are taken as an assumptions for this research.

3.3. Stakeholder analysis

In such a complex system, several actors will be directly involved in the MaaS ecosystem. These actors will probably participate directly in a MaaS system and will share some data. Furthermore, other actors could be involved in the BC ecosystem and AV ecosystem. De Bruijn & Herder (2009), states that the collaboration between different actors in a system is not granted but it is fundamental for their interdependent relationships. In this sense, no actor alone can resolve a complex system on their own. To analyze the actors participating in this system question I.c is answered: *c. Which relevant stakeholders could form part of a MaaS system based on AVs?* For this, a description of their resources, interests, relationships, and roles is conducted.

3.3.1. MaaS provider

The MaaS provider delivers the user a centric MaaS platform that brings to their users with the minimum key services established by Jittrapirom et al., (2017). Furthermore, it acts as an intermediary between the transport operator and the user by using the transport operator data and buying its capacity to sell it to the user (Kamargianni & Matyas, 2017).

This MaaS provider could be a public transport authority, a privately owned company, or even partnerships between them. For this study and to keep a narrow scope only a private MaaS operator is considered for further analysis. This decision is taken based on the interviews provided by Kamargianni & Matyas, (2017) were they establish that private transport operators that use carsharing and on-demand models prefer to give their services with private owned MaaS operators. Furthermore, they also expect that it could take much more time to adopt MaaS models in the public transport sector.

The objective of the MaaS operator is to transform customer requests and handle their data in real-time, in this regard high-speed internet and wide internet coverage are key needed elements (Kamargianni & Matyas, 2017). In this research it is assumed that 5G internet connection will be widely available and it is much faster than current technologies.

An example of an already functioning MaaS operator is the Car2Go platform which operates in the city of Amsterdam. This company rents electric vehicles that can be found all around the city, they charge a minute rate with the idea of reducing vehicle congestion in the city.

Role: Provide a platform, analyze data, provide journey planning, provide payment options.

3.3.2. Transport provider

The transport provider is one of the key enablers to the MaaS provider. They supply transport capacity to have access to a greater market through a MaaS platform. This operator could also be a private company, a public organization, or a combination of both. For this research, this operator is considered a private company that owns a fleet of AVs. This could be an Original Equipment Manufacturer (OEM) of a particular brand of cars. This idea is not new, companies like Tesla are already planning to have a fleet of autonomous taxis that could provide the vehicle as well as the service but at this moment this idea hasn't been implemented yet.

Besides providing the actual vehicle to the MaaS operator, they provide real-time data that enables the operator to satisfy the demand and capacity of their customers. They do this by selling their capacity to the MaaS provider and sending their information usually via a secure Application Programming Interface (API) (Kamargianni & Matyas, 2017).

As mentioned before MaaS operator requires data, the transport operator provides this data enabled by sensors on their fleet and ticketing systems (Kamargianni & Matyas, 2017). In general, the transport operator is the owner of the transport means, in this case, an AV. Furthermore, it should also provide the required services for such vehicles to operate. It is also relevant to consider this stakeholder not only in the supply of vehicles but also in additional services. This makes perfect sense in an AV ecosystem where there is no driver and many more services could be attached to a MaaS like charging services, parking, toll payment, on-board Wi-Fi, magazines, newspapers, music, video, and game services for their passengers.

Role: provide transport means (AVs), provide data, provide additional services.

3.3.3. Data provider

MaaS has a deep dependence on data availability where the role of the data provided is of critical importance for the correct functioning of the system and needs to be done in a fast, secure and reliable way. Furthermore, MaaS needs to capture data from mobile devices, sensors, infrastructure, and its users (Kamargianni & Matyas, 2017). The data operator or also known as data integrator acts as a supplier in the MaaS system by offering data and analytics operations to the MaaS provider.

The data provider acts as the intermediary between all actors in the system. They could be involved in every transaction that involves the access and processing of data. Data from the transport operator could be route planning, contract data, ticketing, payment, and on-demand vehicle data. Furthermore, other providers could also be connected to the data provider like charging stations, tolls, infotainment among others.

The data operator processes the data given by the transport operator and other sources in the system, like data from the user, transport operator, MaaS provider, insurance provider, social media and infrastructure (5G, IoT devices, sensors in the network, and on the road).

Role: Provide data and analytics to the MaaS ecosystem.

3.3.4. Insurance provider

MaaS is a new field that can introduce new business opportunities for insurance companies by expanding their portfolios. Furthermore, nowadays the insurance companies are mostly focused on private vehicle and their passengers but in the last years, companies are expanding to air-passengers' insurance and compensations (Kamargianni & Matyas, 2017). In the case of The Netherlands, it is mandatory to have a third party liability car insurance (WA-verzekering) which usually covers damage inflicted by the car owner with his vehicle to people and property. For this research and as mentioned in the institutional analyses, this is considered as an already developed protection right for the passengers.

Liability in the cases of accidents is currently a controversial topic. As for now the European Commission, (2016) states that the liability for accidents is still on the hand on the driver. Nevertheless, as the technology advances towards a level 5 of autonomy, as the case of this study, the liability will rely on the information provided by the environment.

Role: Provide insurance to vehicles, users, and a third party.

3.3.5. User

The idea of MaaS is fundamentally a user-centered model where it seeks to add value to the user and society (Kamargianni & Matyas, 2017). The use of this kind of service could be regular people, private companies, or both. In this sense and for this work, the user of the MaaS are individuals who need transportation from point A to point B. MaaS creates value for its users by offering them a personalized, affordable, and easy to use mobility solution (Kamargianni & Matyas, 2017).

The acceptance of the use of AVs from the user is also an assumption for this work. Nevertheless, this assumption is not that far away from the current reality. A study conducted by Salonen & Haavisto, (2019) stipulates that the acceptance of current working AVs projects is influenced by its usefulness, ease of use, and social influence. They also specify that positive user perception increases after they have used such systems.

Role: use MaaS

3.4. Conclusions

Analyzing the technical, institutional and stakeholder subsystem is an essential part to answer the first question of this work; *What a MaaS system based on AVs look like?*

By answering the question I it is possible to have an idea of how the main MaaS looks like and its conformed sub-systems. This information is necessary for the next chapter to identify the requirements of the technical, institutional, and stakeholders. Moreover, by analyzing these subsystem it could make clearer to identify where and how blockchain could potentially help to fulfill those requirements.

In the technical sub-system, it is possible to observe the key supporting services that a MaaS system will need to support the main characteristics of this system. These key services are *user identification, planning, booking, payment, ticketing, and real-time information*. In addition to this, it is also relevant to identify the rules and regulations that are in some way delimitating the space design of the proposed system. In this regard's regulations like GPR could have an impact on the design regarding the user data and how is processed within the system. Furthermore, it is also pertinent to identify the major stakeholders that could participate in such a system. These stakeholders have different perspectives, interests, and roles in a MaaS ecosystem, an overview of this is found in *Table 3*.

Stakeholder	Role
User	Use the MaaS system.
MaaS provider	Provide journey planning, payment options, data, and a platform.
Transport provider	provide transport means (AVs), provide data.
Data provider	Provide data and analytics to the MaaS ecosystem.
Insurance provider	Provide insurance to the vehicle, users, and third parties.

Table 3: Stakeholder roles overview.

4. Requirements

In this chapter question II is answered; *What are the requirements needed for the design?* This is achieved by eliciting, categorizing, and prioritizing the requirements needed in order to develop the proposed system. This second phase does not focus on the BC, rather in the requirements needed for a MaaS with AVs, how BC-enabled system design can be executed is presented in the next chapter.

Desk research is conducted based on a system engineering and requirement engineering approach. In section 4.1 a further description of the artifact is presented to identify and outline how these artefacts could help to the objective of this research and be able to elicit its requirements. In section 4.2 the process of requirement engineering is explained and the requirements elicitation, analysis, specification, and validation are done. Finally, a conclusion and answer for this chapter question is present in section 4.3.

4.1. Artefacts

This research proposes multiple IT artefacts which are the result of the design science approach. In this regard, the work of Offermann et al., (2010) identifies eight types of artefacts used in design science; *System design, Method, Language/Notation, Algorithm, Guideline, Requirements, Pattern,* and *Metric.* For this research three types of artefacts are used to support and describe the proposed system design which describes an IT-related system (Offermann et al., 2010). This description could be at any granularity level and in aspects like structure, process and interactions (Offermann et al., 2010). This research results in the creation and delivery of four artefacts. First, a set of requirements which are presented in this chapter and propose a descriptive statement about the system and restrict the design space. Second, a system design that describe the structure or behavior of the BC architecture which is presented in Chapter 5. Third, to support the development of the proposed system a Language/Notation artefact is presented in the form of a BPMN presented in Chapter 6. Finally, to further explore and describe the proposed system a reference architecture is also presented in Chapter 6. The outputs of this research are relevant for design science and can contribute knowledge to the design of a BC-enable MaaS with the utilization of AVs.

The requirements are an attribute of an artifact that is wanted by stakeholders and are used as a guide for the development of such artifact (Johannesson & Perjons, 2014). Moreover, requirements are an assessment of the needs of such systems and what the system should do instead of how should do it. For this work, the requirements represent a description of the services and processes that the MaaS system will provide considering the constraints in their operation.

BPMN is chosen to model in more detail the operational processes and ArchiMate to model at a concept-level or high-level processes of a BC-enable MaaS with the utilization of AVs system concept. In addition to this, ArchiMate can also be useful to promote the re-utilization of infrastructure and applications. These artefacts have the intention to explore what a BC-enable MaaS with the utilization of AVs system concepts look like, their most elemental systems, requirements, and possible configurations.

The ArchiMate model is used to represent the system architecture. The architecture of a system represents the fundamental concepts or properties of a system with its elements, interactions, and relationships in it environment (Maier et al., 2001).

4.2. Requirement Engineering

In this chapter, the requirements of stakeholder, institutional, and technical sub-systems are studied. These requirements describe the services offered by the system and its constraints. This is done with Requirements Engineering that identifies, analyze, document, and examines the constraints and requirements of a system. These could be high-level user requirements and system requirements that are a detailed description of what is expected of the system. Furthermore, these requirements are also classified as functional or non-functional requirements (Sommerville, 2016):

Functional requirement: Are statements of the services that the system must provide, how to react to definitive inputs, and how to react to a specific situation.
Non-functional requirements: Are contains functions or services offered by the system. They are related to the emergent properties of the system hence they apply to the whole system.

In the work done by Sommerville (2016), three main processes are identified when it comes to the requirements engineering process of software systems.

1. *Requirements elicitation and analysis:* This is the process of capturing the requirements of the system by observation, discussions, task analysis among others. It is an iterative process that involves requirement discovery, classification, organization, negotiation, and documentation.
2. *Requirement specification:* This process translates the requirements collected in the previous process by documenting user and system requirements.
3. *Requirement validation:* This process is to corroborate requirements for validity, completeness, realism, consistency, and verifiability.

4.2.1. Requirements elicitation and analysis

For this work, the requirement elicitation phase is done with the knowledge of existing MaaS systems and research work on AVs. This is done with a literature review and desk research that results in the system description proposed in Chapter 3. To further support this and supplement this information, a user scenario is proposed. Scenarios are a description of a particular task to have an idea of how the system can be used. These scenarios are useful to discover what people do, what system they use, and what information they use and generate (Sommerville, 2016). For this scenario, an Uber general trip is used as a reference guidance to come up with the most basic processes that need to be enabled by the system. In addition to this, some examples of things that could go wrong are proposed for such a scenario. While it is impossible to consider all the things that can go wrong on a trip the proposed examples are just a couple that focusses on usability issues. The following scenario is proposed in Table 3:

AV trip hiring scenario	
Initial assumption	A user needs to realize a trip from A to B. They make use of a smartphone to reserve such a trip in a MaaS platform. The user successfully travels from A to B using the MaaS platform and paying for the services used.
Normal	The user creates an account for a MaaS that utilize AVs. Then sets the account with identity information, preferences, and payment options. The user selects a starting point A and finishing point B for that trip as well as the type of the desired car. The car is reserved and proceeds to pick up the user at A. The user enters the vehicle and the trip starts. The trip is finalized when the user gets to the destination at B. The user and the AV finalize the trip and the corresponding payment is charged to the user.
What can go wrong	User forgets the password and can't enter the system. The system should provide the opportunity to recover the user password. The user can't find a free AV for its use. Users should receive an estimated time for when the next vehicle will be available. The user can't find the AV. The AV should provide with specific location of its location and could be helped with sounds or light signals to ease user identification. The user needs to cancel the trip before it started. The system could provide a cancel trip button.

Other activities	The user could buy additional onboard services like Wi-Fi access, video, music, games, drinks, or snacks.
System state on completion	The user is logged on the platform. The trip is completed and the system shows “trip finished” and “payment succeed”. Users can look at details about his trip on completed trips.

Table 4: AV trip scenario.

To further illustrate this scenario, a high-level overview of the user AV trip scenario of the process of creating an account, booking, and using an AV in a MaaS platform is illustrated in Figure 3 as a BPMN model. A more detailed process with all relevant systems, stakeholder and institutional sub-systems model with the requirements and constraints is presented in the next chapter.

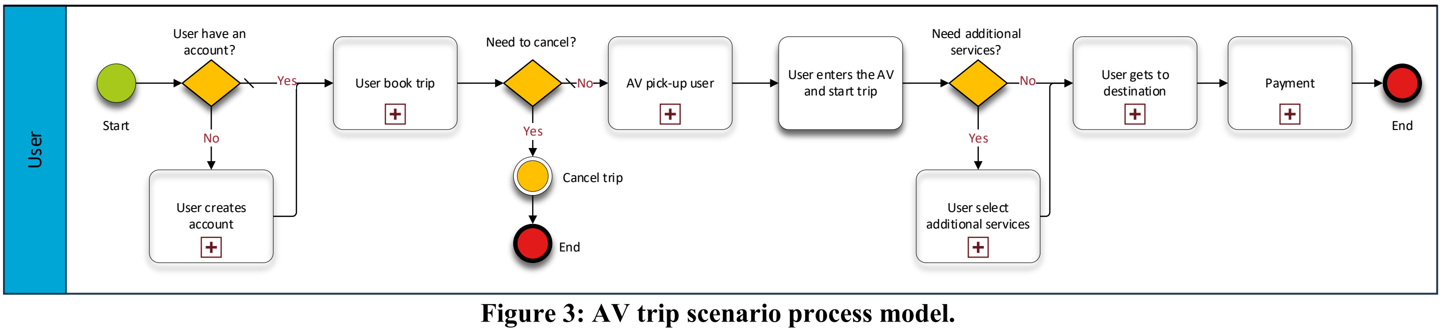

Figure 3: AV trip scenario process model.

The main source of the requirements for this system is deducted from the system description chapter following with a case scenario to further illustrate the process of using a MaaS system to realize a trip. These requirements are documented in the next chapter.

4.2.2. Requirements specification

The requirement specification process is done to document user and system requirements. These should be written in a clear, consistent, complete, unambiguous, and easy to read way (Sommerville, 2016). First, the identification of constraints is conducted. These constraints could provide relevant insights into key issues or requirements that must be addressed by the system. These constraints are documented in *Table 5* and are derived from the system description previously mentioned as well as the objective and goal of this research.

	Constraint	Justification
External Constraint	Data processed must be compliant with GDPR.	Current European GDPR legislation.
	Data gathering must be compliant with GDPR.	Current European GDPR legislation.
System Constraint	Service must be provided by AVs.	Interest for this research.
	The system must provide its services in one platform.	Core characteristics of a MaaS system.
	The system must use Level 5 Autonomous Vehicles.	Fully autonomous, no driver is needed.
	The system must use 5G connectivity.	Required for Level 5 Autonomous Vehicles
	The system needs extensive geographical availability in the city of Amsterdam.	To be able to use the system in the whole city.
	The system must run on mobile infrastructure.	Meets mobility constraints.
	The system must use a carsharing model.	Interest for this research.

User Constraint	Service must be offered by means of smartphones or wearable devices.	Meets mobility constraints.
	The system must be trusted, provide security, and protect the privacy of the users.	Most relevant issues for the use of Autonomous Vehicles.
Institutional Constraint	Users must be able to use AVs as passengers.	No need for a driver.
	AVs should be able to transit on public roads.	Broad reach for services.
	Liabilities and insurances should be able to protect users and third parties in case of accidents.	Protection of users in case of accidents.

Table 5: Constraints

Following the constraints, the user requirements are identified. These are statements of what services and functionalities the system is likely to deliver to the user of such a system (Sommerville, 2016). These requirements are presented in Table 5. They are provided with a unique identifier to keep track of them. Furthermore, the source of the requirement is identified to see if they are from the technical, institutional, or stakeholder subsystems. Moreover, a justification for each requirement is also explained in this table.

ID	Source	Requirement	Justification
U1	*Technical*	The system shall provide the user with the ability to create a unique account to enable access to the platform and its services.	User needs an account and ID to access the services of the platform.
U2	*Technical*	The system shall allow the user to plan a trip according to his preferences.	Personalization is a core characteristic of MaaS.
U3	*Technical*	The system shall users to book their trips.	User needs to book their trips and it is a core characteristic.
U4	*Technical*	The system shall provide access to real-time information for its users.	Services are needed in real-time.
U5	*Technical*	The system shall provide payment options and means for its users.	Payment options and means are needed for providers to make a business and user to pay for the services offered by those businesses.
U6	*Technical*	The system shall provide a ticketing system for its users.	When a user book a trip, the assigned AV must be reserved to him and not used for other users.
U7	*Institutional*	The system shall comply with GDPR regulations.	Data protection regulations.
U8	*Stakeholder*	The transport provider shall provide users access to AVs, additional services, and access to real-time information.	The transport provider must provide transport means and information to users.
U9	*Stakeholder*	The MaaS provider shall provide a platform that enables its users to plan their journeys and payment options.	MaaS systems use a digital platform, it is a core characteristic.
U10	*Stakeholder*	The data provider shall provide the system with secure data and analytics.	The data provider acts as a data intermediary in the ecosystem.
U11	*Stakeholder*	The insurance provider shall provide insurance to AVs, users, and a third party.	Laws and regulations specify the need for insurance.
U12	*Stakeholder*	The system shall be trusted by the users.	Increase adaptation rate and usability.

Table 6: User requirements

The system requirements provide a thorough description of the system services and functions that should be implemented (Sommerville, 2016). These system requirements are presented in Table 6 and follow the same structure proposed in the user requirement and represent a further detailed description that comes from these user requirements. In addition to this, the type of requirement is documented, F means the requirements is a functional and NF means it is a non-functional requirement.

ID	Source	Type	Requirement	Justification
S1.1	Technical	F	The system shall enable user registration.	Registration is required to have an ID and user preferences.
S1.2	Technical	F	The system shall enable the user to personalize his account according to his preferences.	It is a core characteristic of MaaS.
S1.3	Technical	F	The system shall provide the user with a unique ID.	A unique identifier is needed to relate the user in different transactions.
S1.4	Technical	F	The system shall enable the user to access the services provided.	User needs access to services to use them.
S2.1	Technical	F	The system shall enable the user to plan a trip by filtering: type of road, fastest route, avoid tolls, cheapest, time.	Provide options to the user to plan their trips.
S2.2	Technical	F	The system shall enable the user to select the number of passengers.	The number of passengers is relevant for capacity and insurance purposes.
S2.3	Technical	F	The system shall enable the user to select the type of AVs.	If different sizes of AVs are offered user must be able to select according to his preferences.
S2.4	Technical	F	The system shall enable the user to select a starting point.	Needed starting location to route planning.
S2.5	Technical	F	The system shall enable the user to select an ending point.	Needed ending location to route planning.
S3.1	Technical	F	The system shall enable the user to reserve a trip.	Needed to lock an AVs to a specific user.
S3.2	Technical	F	The system shall enable the user to cancel the trip.	If the user must cancel the trip for any reason.
S3.3	Technical	F	The system shall enable the user to choose a route.	The user might want to use a particular route.
S4.1	Technical	F	The system shall provide the user with real-time information.	A core characteristic of MaaS.
S4.2	Technical	F	The system shall provide the user with high-speed connectivity.	High speed is needed for AVs and real-time information.
S4.3	Technical	F	The system shall provide extensive geographical availability in the city of Amsterdam.	To get coverage in the whole city of Amsterdam.
S5.1	Technical	F	The system shall provide online payment solutions.	All systems transactions are online.
S5.2	Technical	F	The system shall provide cashless payment solutions.	All systems transactions are online.
S5.3	Technical	NF	The system shall be easy to use.	Easy access to lower entry barriers.
S5.4	Technical	F	The system shall provide the ability to track payments.	The user might want to check his payments or report them.

S6.1	Technical	F	The system shall provide an identification of the AV for the user.	The user needs to recognize which is his vehicle.
S6.2	Technical	F	The system must allow the AV to recognize clients via smartphone, smartwatch, or wearable device.	Means for the AV to find the user.
S6.3	Technical	F	The system must allow the user to AV via smartphone, smartwatch, or wearable device.	Means for the user to find the AV.
S6.4	Technical	F	The system must allow the user to gain access to the AVs.	The user would need to unlock the car to enter.
S6.5	Technical	F	The system must enable the AV to let the user in.	AV will need to be unlocked by the user to board it.
S7.1	Institution al	NF	The system must consider privacy by design.	User data could be sensitive and should comply with GDPR.
S7.2	Institution al	NF	The system must consider data minimization and purpose limitation regarding user data.	GDPR principles for processing personal data.
S7.3	Institution al	F	The system must notify the user if personal data is a breach.	GDPR breach notification compliance.
S7.4	Institution al	F	The system must allow the user to access his personal data.	GDPR right of access compliance.
S7.5	Institution al	F	The system must allow the user to delete his data.	GDPR right to erasure compliance.
S7.6	Institution al	F	The system must ask for consent for data gathering and processing.	GDPR affirmative consent compliance.
S8.1	Stakeholde r	F	The system must offer transport operator capacity to the users.	To offer AVs to the users.
S8.2	Stakeholde r	F	The system must allow the transport provider to offer additional services.	To offer additional services to users, like Wi-Fi, music, video, games, etc.
S8.3	Stakeholde r	F	The system must enable transport payments for additional services.	Payments for additional services are needed.
S8.4	Stakeholde r	F	The system must be able to receive and process transport provider data.	A core characteristic of MaaS.
S9.1	Stakeholde r	F	The system must provide a unique central platform.	A core characteristic of MaaS.
S9.2	Stakeholde r	F	The system must be able to receive and process data from the MaaS provider.	A core characteristic of MaaS.
S10.1	Stakeholde r	F	The system must be able to receive and process data from the data provider.	A core characteristic of MaaS.
S10.2	Stakeholde r	F	The system must be able to receive data securely and reliably.	To ensure data granularity.
S10.3	Stakeholde r	F	The system must be able to capture data from users.	To offer personalized services.
S10.4	Stakeholde r	F	The system must be able to capture data from the infrastructure.	Data from infrastructure is needed to provide key services.
S11	Stakeholde r	F	The system must be able to receive and process data from the insurance provider.	Data such as payments, AV telemetry, and infrastructure could be useful for liabilities purposes.
S12	Technical	NF	The system must support a diversity of actors.	Able to support a multi-actor system.

S13	Technical	NF	The system must be scalable.	Possibilities of further expansion of the system.
S14	Technical	F	The system must be able to take transactions automatically.	Transactions are needed between all the stakeholders.

Table 7: System requirements

4.2.3. Requirement validation

The process of requirement validation consists of inspecting whether the requirements reflect the expectation of the user and find possible issues. Furthermore, this process is of significant relevance for requirements documentation because it can lead to further issues during the implementation or use of the system and services (Sommerville, 2016).

To do this process several checks are done, among these, conducting validity checks to determine if the requirements reflect the needs of the system users. In this part, some errors were detected in the AV trip scenario process model proposed in Figure 3, due to this the process was revised and corrected iteratively three times. Moreover, consistency checks are also conducted to determine that the requirements are not conflicting, are not contradictory and requirement descriptions do not differ for the same system function. In this part overlapping requirements were detected and corrected, for instance, some requirements for the MaaS provider stakeholder were removed because they were already documented by the analysis of the technical sub-system and the AV trip scenario process model. In addition to this, requirements for the institutional sub-system were also overlapping by the same GDPR article and where corrected them by proposing only one requirement that involves two or more articles.

Unfortunately, it is hard to demonstrate how a set of requirements could really meet users need. By the same token, all requirements issues are rarely found in the validation process and additional requirements changes are needed to correct oversights and mistakes (Sommerville, 2016).

4.3. Conclusions

In this chapter question, II is answered: *What are the requirements needed for a MaaS system based on AVs?*. This is done by analyzing the results from the three sub-system description conducted in Chapter 3. This chapter is done to identify the requirements needed for the creation of an artifact where a broad description of how such artifact would look like is presented in section 4.1. Furthermore, a set of requirements is presented in section 4.2 with a detailed process on the requirement engineering done to elicit, analyses, specify, and validate such requirements. This chapter is needed to design a BC-enabled MaaS system based on AVs and be able to design its architecture in the next chapter.

5. System design and develop

In this chapter, the third phase of this work is conducted and question III is answered: *What does a BC-enabled MaaS system architecture look like?* For this, the output from the previous chapter which are the requirements needed for a MaaS with AVs, are used as inputs for this chapter. This chapter is done in four sub-phases, the idea generation or improvement of existing ones is conducted in section 5.1. The ideas generated in the previous section are assessed and selected in section 5.2. In addition to this, an initial sketch of the artefact is presented in section 5.3 with the selected ideas from the previous section. Finally, the design decisions are justified in section 5.4 along with a reflection to prepare for the next phase of this work.

The design of a system is about fulfilling the defined requirements in a design that is intended to solve a problem. For this, the work of Johannesson & Perjons (2014) proposes four main steps that are used in this research:

1. *Imagine and Brainstorm:* idea generation or elaboration of existing ones to inform the design of the artefact.
2. *Assess and Select:* the ideas of the previous step are assessed and selected to continue the design process.
3. *Sketch and Build:* this step is about to construct the design of the artefact.
4. *Justify and Reflect:* the design decisions made in the process are justified and reflected upon.

The first two steps of this process also form part of the design of the artefact and the decisions made throughout the development can also be seen as design decisions for such artifact (Johannesson & Perjons, 2014). In the next sections, these steps are detailed.

5.1. Imagine and Brainstorm

The step of imagine and brainstorm is about idea generation, especially the creation of design alternatives that aim to solve the problem uniquely stated in this work. This step also prepares a solution space with possible ideas or solutions for the problem defined in this work. Furthermore, this section aims to answers question III. a *What are the design options to consider?* To answer this question a divergent thinking strategy is used on this step followed by convergent thinking in section 5.2 of this chapter.

One path to do this could be considering all the requirements proposed in the previous chapters and a set of solutions for each requirement. Due to the time limitations of this work, this path is less feasible. Instead, the requirements from the user perspective are considered, especially the design decision that could enhance the trust, security, and privacy of the system for its users. The main objective of this research is to get an initial insight into how a Blockchain-based Mobility-as-a-Service operated on Autonomous Vehicles concept design would look like. For this BC architecture design choices that fulfill the requirements are explored. To guide this, the work of Tasca et al., (2017) is used as a standard technical reference model of BC architectures. Furthermore, their work is also used to explore, evaluate, and compare different system design options.

BC is an interesting solution for this work because of its fundamental principles of transparency, decentralization, privacy, and security (Aste et al., 2017). Additionally, BC can be used to develop a secure, trusted, and decentralized autonomous ITS ecosystem (Yuan & Wang, 2016). In regards to decentralized architecture, BC can help to protect users privacy from global surveillance of corporations and states (De Filippi, 2016). Furthermore, BC enables new ways of distributed software architectures where decentralized and transactional data can be established to untrusted members eliminating the need to rely on a single integration point (Xu et al., 2017).

The work of Tasca et al., (2017) classifies the main blockchain components and their relationships, this helps to explain how blockchains works and design or model a blockchain concept. These main components are:

1. *Consensus mechanism*
2. *Transaction capabilities*
3. *Native currency/tokenization*
4. *Extensibility*
5. *Security & Privacy*
6. *Identity Management*
7. *Charging and Rewarding system*

Each of these components has sub-components with different layouts that represent design decisions to be made to design a BC-based MaaS system with the adoption of AVs. In the next section of this chapter, these different design decisions are assessed to then select the layout that best fits with the requirement for the design of this system.

5.2. Assess and Select

In this phase of the design, the ideas or solution space explored in the previous phase are assessed and selected for the development of the artefact. This phase can be seen as a systematic exploration of the solution space identified in the previous phase (Johannesson & Perjons, 2014). Additionally, to guide this phase the requirement defined in the previous chapter are considered with the objective of satisfying them.

5.2.1. Consensus mechanism

One main component of BC design is the consensus. This is a group of procedures and rules that preserves and updates the ledger with the idea of ensuring the trustworthiness, accuracy, authenticity, and reliability of the records in the ledger (Tasca et al., 2017). This group of procedures and rules have other components and sub-components that are assessed to identify what layout offers the best fit for the requirements. The network topology of a BC could be public, private, or consortium.

Some of the requirements for the proposed system are related to latency and trust, more specifically requirements U4, U8, and S4.1. Moreover, these requirements demand a low latency system to reach real-time operations and a system that the users can trust. These requirements are relevant for considering the network topology of a BC system and demand a fast consensus mechanism for the system. In contrast, permissions-less or public network topologies are one of the most secure ones but with inherent latency issues (Casino et al., 2019; Tasca et al., 2017). This leaves out with two other topology choices; private and consortium topologies. Private and consortium topologies possess comparable scalability and privacy protection but consortium topologies select a group of nodes instead of a single one with access to transaction processes as used in the private topology (Casino et al., 2019).

The proposed system in this work is formed with a group of stakeholders that will need access for different transactions which are reflected in requirements U8, U9, U10, and U11. This entails that the only feasible option that can fit the requirements for multiple nodes or stakeholders is a Consortium or Federated network topology. By doing so, this selection locks some of the other options when considering the consensus mechanism of the BC architecture. The Consensus Immutability and Failure Tolerance list of choices is predetermined by the network topology previously chosen. This entails that only a limited number of nodes will have reading and approval rights. Moreover, only a Practical Byzantine Fault Tolerance (pBFT) mechanism can perform in network topologies with a handful of identified nodes with permission to authenticate transactions and offers low latency capabilities (Castro & Liskov, 2002). This is relevant because an important element to consider when using AVs are latency issues.

The design choices of a Consortium network topology with a pBFT mechanism are reinforced with requirements regarding the real-time operations needed for the system. Furthermore, the system needs a shared or global truth for all the nodes to agree up, this is called Agreement and defines the probability of reaching consensus (Tasca et al., 2017). In this regard, the pBFT is a deterministic consensus mechanism (Castro & Liskov, 2002) thus, the type of agreement for reaching consensus should be a deterministic one. This consensus mechanism work by allowing the replicated system to tolerate faults if 1/3 of the replicas turns faulty inside a window of vulnerability (Castro & Liskov, 2002). Moreover, pBFT enables high transaction throughput in the case that consortium nodes are functioning as ordering nodes.

The pBFT mechanism structure is formed by one primary node and additional secondary nodes and the goal is to reach consensus for the state of the system (Castro & Liskov, 1999). Moreover, the primary node could be substituted if it is affecting the request-response times, this is achieved by also a voting consensus mechanism between the majority of the participating nodes (Castro & Liskov, 1999). This consensus mechanism works in 4 phases:

1. A request is sent to the primary node by the client.
2. This primary node transmits the request to the secondary nodes.
3. All the nodes process the request to send it to the client.
4. The request is completed when the allowed number of faulty nodes plus one, replies with the same results.

To further illustrate how this process works, *Figure 4* is proposed to show the normal case of primary faults. In this figure, U represents the user followed by the Primary and secondary nodes were one of the last ones is faulty.

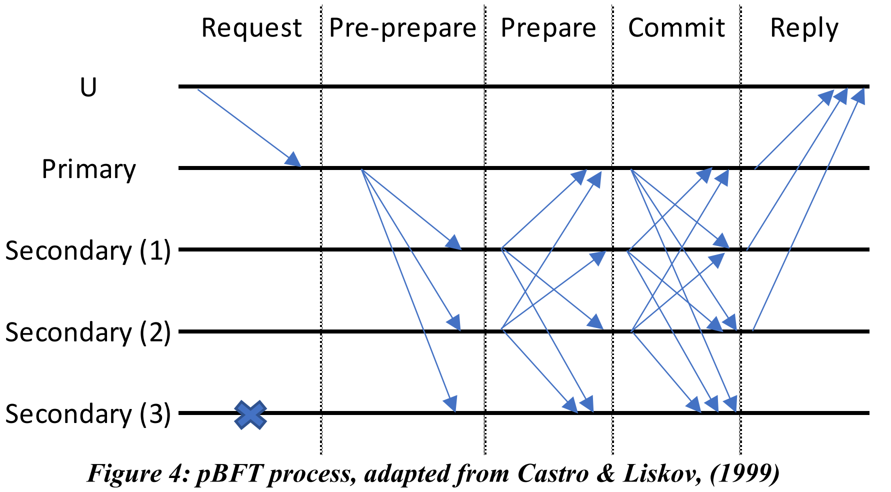

Figure 4: pBFT process, adapted from Castro & Liskov, (1999)

The BC design of the consensus for this work should look like a Consortium network topology with a pBFT consensus mechanism. Furthermore, a Deterministic agreement is selected to enable access to real-time information and payment options like a smart contract.

5.2.2. Transaction capabilities

The transaction capabilities relate to the scalability of transactions and the possible use in applications and platforms (Tasca et al., 2017). These transactions are signed by at least one participant, they can be a transfer of digital or physical assets, finalization of a task, etc. (Casino et al., 2019). The proposed system has some requirements regarding the transaction capabilities of this design. Moreover, requirements U4 and U8 specify a low tolerance for latency and demands high transaction capabilities. Furthermore, requirements U5, U8, S5.1, S5.2, S8.1, and S8.2 introduce a demand for additional services and online cashless payment solutions for such services. In addition to this, scalability requirements (S13) also form part of the system design to enable the system for future expansions.

The transaction capability demands of this system are low latency in transactions with a high transaction throughput. Additionally, online cashless payment options that can support the main and sub-services offered to the ecosystem of the platform. In this regard, BC solutions can reduce transaction costs, increase safety, transparency, and speed (Casino et al., 2019).

Only a couple of design alternatives are available that fit with the previous network topology choices and the requirements previously mentioned. This is the case of the data structure in the block-header which describes the ability of the system to store transaction information (Tasca et al., 2017). In this case, the only available option to consider that works with a Consortium topology is the Patricia Merkle Tree. This type of data structure allows to insert, delete, or edit information in the balance of the accounts and allows faster and flexible transactions (Tasca et al., 2017). This design decision is also reinforced with the latency requirement of the proposed system. With the same argumentation, the only server storage layout that is compatible with a Consortium topology is the Thin Nodes Capabilities (Tasca et al., 2017). With this design choice, only some of the connected nodes in the network contain a part of the information stored in the BC (Tasca et al., 2017). This layout for the server storage also creates a more scalable system (Tasca et al., 2017) which is also aligned with requirements U8 and S13.

Another relevant requirement regarding the transactions is the ability of the system to process these transactions automatically (S14). For this smart contracts could be useful, because there is no need for human interaction, confirmation, or mediation (Tasca et al., 2017). Moreover, conflicts or duplicated transactions are not stored in the BC and are automatically reconciled (Tasca et al., 2017). The smart contract offers several automation properties that fit with the requirements of this design, such properties as self-enforceable, self-executable, self-verifiable, and self-constraint (Clack et al., 2016).

5.2.3. Native currency/tokenization

The use of native currency and tokenization allows the use of asset-transfers for different use cases with BC technology, this technology has underlying native assets or tokens that enable activities on platforms or communities (Tsukerman, 2016). Tokenization could be used as a digital bearer bond and its ownership is resolved by the data rooted in the BC, they can be transferred between holders and do not require the approval of authorities (Tasca et al., 2017).

The proposed system has requirements to support a diversity of actors (S12). To fulfill this requirement a convertible multiple asset layout is needed because this allows exchanging assets with others outside the platform with a diversity of currencies (Tasca et al., 2017). By doing so, allows multiple actors with different currencies, this could reduce the entry barrier for the users in the system while satisfying requirement S12.

In addition to this, the proposed system has several requirements for access, book/ticketing and payment options (U1, U8, S1.4, S6.4, S6.5, U3, U6, S3.1, U5, U9, S5.1, S5.1, S8.3). This entails that the system could use tokenization as a mean of payment to gain access to the AV and book an AV, thus some form of a ticket that represent these actions is demanded from the system. Regarding this, the work of Oliveira et al., (2018) identifies three classes of tokens; Coin/Cryptocurrency, Utility Token, and Tokenized Security. Moreover, cryptocurrencies are asset-based token used as digital money. Tokenized Security is used as a digital share that possesses entitlement to profit or dividends. Among these, the only class of tokens that has the purpose needed for this system, access permission, is the Utility Token. Moreover, Utility Tokens are meant to pay a fee for access or pay-per-use platforms as well as reward user behavior and experience in such platforms (Oliveira et al., 2018).

5.2.4. Extensibility

Elements like interoperability, intraoperability, and governance can help to take a look at the future ecosystem of the BC network and its integration potential (Tasca et al., 2017). The interoperability shows the capability of BC to exchange information with other systems that might or not be blockchain-based systems (Tasca et al., 2017).

Moreover, it allows independent and secure real-time payment services providing a complement to public and private transportation systems (Christidis & Devetsikiotis, 2016). Next, intraoperability shows the capability of the BC to trade information with other BCs systems (Tasca et al., 2017).

The proposed system has multiple requirements that illustrate the need for the system to exchange information with other systems and technologies (U8, U9, U10, U11). Furthermore, some requirements demand an exchange of information between different stakeholders that form part of the ecosystem like Transport Providers, Data Providers, Insurance Providers, among others (U8, U9, U10, U11). In addition to this, other system requirements demand the exchange of information inside the system like access to services, devices, data, and transactions (S1.4, S6.2, S6.3, S8.1-S8.4, and S11). These extensibility components for the architecture of the BC are explicitly illustrated in the requirements. Consequently, the only possible layout for the proposed system is to consider Explicit Intraoperability and Explicit Interoperability components.

Another relevant component to consider for the system extensibility is governance rules. These are decisive elements for its successful implementation, adaptation, change, and interaction (Tasca et al., 2017). The work of Tasca et al., (2017) identifies two types of governance rules, the Technical Rules of self-governance, this is formed by protocols, procedures, software, supporting facilities among others. In addition to this, Regulatory Rules are defined by external entities and formed by industry policies, regulatory frameworks among others. Moreover, this research identifies multiple system technical requirements, this entails that the consortium of stakeholders in the ecosystem must satisfy these technical requirements and rules. For this, a layout of the governance would need to be composed of different stakeholders that work together to develop commercially and technologically for common profit. In this regard, the only option that considers this is an Alliance Mode were only nodes that meet certain criteria (like permission to write or read in the BC) are approved to collaborate to set the technical rules of the BC (Tasca et al., 2017).

5.2.5. Security and Privacy

A way to secure data is to use data encryption which is a cryptographic tool that is used to hash and validate information, making the system more or less versatile (Tasca et al., 2017). Whereas security is inherent to BC technologies because there is no single point of failure, some research shows that BC transactions can be susceptible to information extraction and even identification of the participants (Tasca & Liu, 2016). Similarly, multiple solutions exist to encrypt data and keep this data obfuscated, this is by making a program into a "black box", intending to deny access to data and processes (Tasca et al., 2017). In this regard, components like security and privacy are closely related. The privacy of information is the ability to control the use and procurement of people personal information (Westin, 1967). BC does not fully secure user privacy because most BCs transactions are pseudonymous and the identity of the origination and recipient can be exposed (Rossi et al., 2019).

There are multiple requirements identified in this work that relates to the need for data security and privacy for the system (U7, S7.1-S7.6, U10, and S10.2). While BC does not fully solve these issues, some design considerations can help to mitigate them. For this purpose, privacy concerns can be satisfied by the inclusion of smart contracts that can automatize transactions thus reinforcing this decision by satisfying requirement S14. Nevertheless, these smart contracts could include personal information of passengers in the case of MaaS systems (Nguyen et al., 2019). For this reason, a Zero-Knowledge - Succinct Non-interactive Argument of Knowledge (ZK-SNARKS) can be used to validate terms without revealing private information in the smart contracts (Nguyen et al., 2019). Furthermore, such a solution does not require a public key for validation, being the design of this research a consortium network topology where there are no public entities with permission (Tasca et al., 2017).

The previous design decision of using a pBFT consensus mechanism is reinforced regarding the need for security of the system. This is due to the properties of the pBFT regarding security. According to Castro et al., (2002) this consensus mechanism poses a good performance, it is safe to use in an asynchronous environment like the Internet, has defensive mechanisms for Byzantine-faulty clients and it is proactive to recover replicas.

Furthermore, pBFT also offers linearizability that is a robust safety property without the need to rely on synchronous assumptions (Castro et al., 2002).

Another way to mitigate privacy vulnerabilities of the system is the practice of not including private data on the BC. Nevertheless, this entails that the system would need to use a digital identity that does not track back to personal data or a tokenization mechanism. Moreover, this is already discussed before and reinforces the design decisions of using tokenization and also a digital identity that are aligned with requirement U1. Similarly, one of the requirements regarding privacy is to comply with GDPR regulations (U7). Specifically, BC does not fully comply with GDPR regulations due to the property of immutability of the data in the BC and according to GDPR, personal data must be able to be forgotten. For this reason, the need of not storing personal data in the BC is further strengthened and validated to satisfy system requirements and regulatory rules.

5.2.6. Identity Management

The identity management component is formed by two layers; the Access and Control layer and the Identity layer. They ensure access to sensitive data and determine the governance model of the BC (Tasca et al., 2017). Regarding the access and control layer, it is relevant to establish an adequate governance structure while considering the ledger construct (Tasca et al., 2017). In this regard, the governance structure regulates control policies management and authorizations which are rules that manage users, systems, and node permissions on the BC (Tasca et al., 2017). This is represented in rules that determine who has read and write access and who can manage the consensus in the ledger.

In this research, several requirements that relate to access and control demands are detected (U3, U8, U10, and U11). These requirements demand that some stakeholders have control and access to information on the BC. For instance, the data provider should have read and write access to process and send new data to other stakeholders in the ecosystem while complying with requirement S7.1. Therefore, the system demands specific access and control for each of the stakeholders or nodes that participate in the system. In this regard, only a private BC allows a pre-selected group of participants to supply and maintain the BC integrity (Tasca et al., 2017).

Multiple requirements relate to identity management, there is the need for a unique ID (U1) and use this ID to gain access to different systems and services (U2, U3, U5, and U6). In addition to this, other system requirements demand to use this ID (S1.1-S1.4) for payments (S5.4), user identification (S6.1 and S6.2), and exchange of information with different stakeholders in the ecosystem (S8.x-S11). In addition to this, user requirements demand a system that can be trusted (U12). These requirements illustrate the emphasis of using BC for digital identities. Digital identities can provide security, data integrity, and anonymity without the need to rely on third parties (Yli-Huumo et al., 2016). In this regard, digital identities have become a fundamental security measure (Rivera et al., 2017).

The requirements listed above demand a need for the identity layer where information can be trusted and verified. Therefore, when looking at the identity layer of the BC, onboarding and offboarding of nodes are key aspects that need consideration (Tasca et al., 2017). These can be achieved by implementing identity verification processes, like Know-Your-Customer (KYC) and Anti-Money-Laundering (AML) that can increase transparency and verify user information (Tasca et al., 2017).

5.2.7. Charging and Rewarding System

Operational and maintenance costs of the BC systems are usually covered by the members of the network and it is done by different models depending on the architectural configuration, governance, data structure, and computation required on the chain (Tasca et al., 2017). To cover these potential financial costs of running a BC platform an incentive scheme could be used to maintain the cost structure for different stakeholders (Tasca et al., 2017). For this, the work of Tasca et al., (2017) identifies two sub-components; Reward System and Fee System.

The Reward System is a rewarding mechanism that functions automatically and generated by BC systems to retribute for verifications, validations, or data storage in the network (Tasca et al., 2017). As mentioned before, this system uses pBFT as a consensus protocol for validating transactions.

Regarding the nodes, the work of Yuan & Wang, (2016) states that BC could be used to include all the available computing elements in the ecosystem. In this proposed system various computing elements can act as nodes in the network. In particular, the AVs could be used as nodes to validate route information and transactions. It is possible to already see examples of this in the case of the BC model Block-VN proposed by Sharma et al., (2017) where they allow vehicles to realize and use their resources to develop a vehicular network to produce services. In addition to this, IoT devices in the infrastructure and smart devices from the users could also be used as nodes. By doing so, the system could increase further participation of the nodes and fulfilling requirement S12 by proposing a reward scheme that compensates participants with a token that could be used to buy services in the ecosystem. The user or AVs that opt to participate in the network by providing their computer power could be rewarded with these tokens. In addition to this, some BC networks introduce a fee system when users make use of the BC, nevertheless, this is not necessary. Moreover, this is aligned with requirements S12 and the intention to reduce the entry barrier for the users.

5.2.8. Design decisions overview

The BC architecture for a BC-based MaaS system with the adoption of AVs consists of a set of components and sub-components that are designed with the intention of fulfilling the design requirements in section 4.2.2. A summary of what requirements support the design decision is presented in Table 8. Moreover, the BC architecture needed for the proposed system in this research is based on a Consortium network topology with a pBFT consensus mechanism and a Deterministic agreement. Additionally, the server storage layout of the system is a Thin Nodes Capabilities layout and a Patricia Merkle Tree for the data structure with the utilization of Smart Contracts for payment purposes. Furthermore, Utility Tokens are used as tokenization of the system with the ability to Convert Multiple Assets to allow a diversity of actors in the system. In addition to this, Explicit Intraoperability and Interoperability are selected as a way to increase the integration potential of the system in an Alliance Mode of stakeholders. To increase privacy and security in the system a ZK-SNARKS encryption tool is selected. To manage the identities of the system a Permissioned Private BC design decision is further reinforced with a KYC/AML identity verification process. Finally, a reward system is selected were participant nodes can get tokens in exchange for computer power to validate the transactions in the system without incurring in any fees for the users.

It is relevant to mention that some of the requirements in section 4.2.2 were left out of the design decisions for the BC architecture. These requirements where operational ones (S2.1, S2.2, S2.3, S2.4, S2.5, S3.2, S3.3, S5.3) or general requirements (S4.2 and S4.3) that do not have any impact on the design decision for the BC architecture of this research.

Component	Design decision	Requirements
Consensus Mechanisms	Hierarchical or Consortium	U4, U5, U8, U9, U10, U11 and S4.1
	Practical Byzantine Fault Tolerance	
	Deterministic	
Transaction Capabilities	Patricia Merkle Tree	U4, U5, U8, S5.1, S5.2, S8.1, S8.2, S13 and S14
	Thin Nodes Capabilities	
Native Currency/Tokenization	Native Asset	U1, U3, U5, U6, U8, U9, S1.4, S3.1, S5.1, S6.4, S6.5, S8.3 and S12
	Tokenization	
Extensibility	Explicit Intraoperability	U8, U9, U10, U11, S1.4, S6.2, S6.3, S8.1-S8.4, and S11
	Explicit Interoperability	
	Alliance Mode	
Security and Privacy	ZN-SNARKS	U7, U10, S7.1-S7.6, S10.2 and S14
	Built-In Data Privacy	
Identity Management	Permissioned Private Blockchain	U1, U2, U3, U5, U6, U8, U10, U11, U12, S1.1-S1.4, S5.4, S6.1, S6.2, S7.1, S8.x, S9.x, S10.x and S11
	KYC/AML	
Charging and Rewarding system	No Fee	S12

Table 8: Design decisions and requirements.

5.3. Sketch and Build

In this phase of the system design and development a sketch of the artefact is presented. This is done with the selected ideas presented in the previous section with the objective of answering question III: *What does a BC-enabled MaaS system architecture look like?*. The illustration of the artefact is presented in mainly three figures; the BC architecture, an overview of the core functions, and the overall structure of the system. This section is relevant to improve thinking about the artefact, provide guidance, and facilitate communication for the stakeholders that could be involved in the construction of such artefact (Johannesson & Perjons, 2014).

5.3.1. BC Architecture

BC architecture is formed by various components and sub-components that are described and selected in section 5.2. To further illustrate the BC architecture selected for this research, *Figure 5* is presented as a summarized overall view of the design choices selected to develop a BC-enabled MaaS system for the utilization of AVs. In this figure, the top part represents the main components followed by the sub-components. Next, in the bottom are the selected design choices that are used to design the BC architecture of the proposed system in this research.

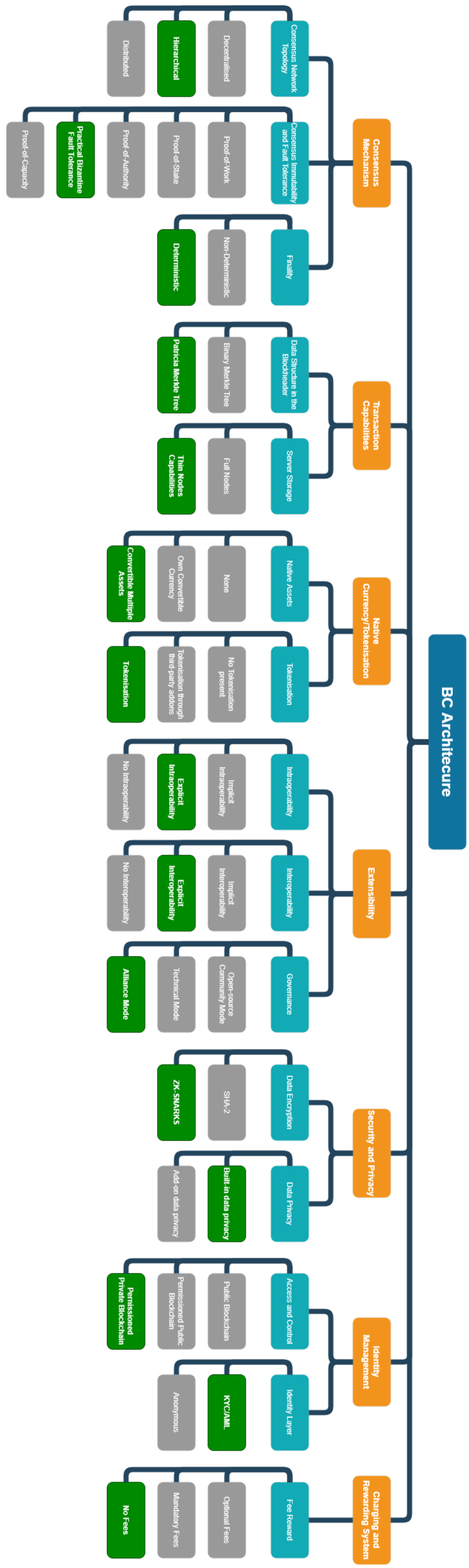

Figure 5: BC Architecture, adapted from Tasca et al., (2017)

5.4. Design justifications and rationale

In this phase of the design, the design decisions are reflected upon to improve future development and design. Additionally, a design rationale is also presented to justify design decisions, the reason behind such decisions, and potential drawbacks in the design. Moreover, the design rationale could be of great value for the following research project on the topic and could support the designer to avoid dead ends and other problems (Johannesson & Perjons, 2014).

While the major design decisions regarding the BC architecture taken for this work are expressed and explained in 5.2 some of the component identified by Tasca et al., (2017) are discarded. This is the case of the consensus component where full permissionless or public network topology was not selected. Despite the fact, that this is the most secure choice it is not feasible for this work due to latency issues. Furthermore, this is a strong design reason for various design choices of the architecture in which latency requirements are treated with a higher priority due to the core characteristic of a MaaS system. This is also the case of the transaction capabilities of the system where latency is considered as a priority. Moreover, transaction throughput is a major challenge for BC technologies in comparison with traditional transaction means like Visa or PayPal and the system demands high transactions per second.

Other components that were discarded for this work are the scripting language and the codebase for the system. This decision is taken due to the scope and high-level point of view of this research. For instance, the Scripting Language is too specific and technical to analyze in this work. Although the scripting language is not considered, it cannot be Touring Complete due to previous design choices. Similarly, the Codebase of the system is also not considered due to its level of detail scaping the high-level view of this work. In addition to this, the Locality component is also discarded due to the scope, nevertheless, the locality of the system could be extended to surrounding areas of Amsterdam in the future.

The rewarding system and the idea of using the AV as computing nodes to authenticate transactions is also something worth mentioning. Although computation and latency need for AV can be provided by units like GPUs, there is a high associated power cost and thermal constraints that greatly impact the driving range and efficiency of the vehicle (Lin et al., 2018). Furthermore, the work of Lin et al., (2018) demonstrate that computational capabilities are still a bottleneck to further increase system accuracy. The design rationale behind this decision is to assume that when AV reach the level 5 (as mentioned in 1.1) of autonomy in the near future, computing power and efficiency of the several ECUs units in the AV would be sufficient to be able to validate the transaction using the pBFT consensus mechanism.

Another relevant design justification regarding the insurance provider for the system is taken for this research. To further explore the idea proposed in 3.2.2 regarding the insurance provider for the system, for liability purposes it is assumed that the regulations are up to date in the time of realizing the proposed system. In this regard, it is considered that the transport provider pays an annual fee for insurance services. Moreover, as the AV relies on the surrounding infrastructure to make driving decisions it is possible to consider the liabilities for the insurance to the AV instead of the user. Considering the level 5 of autonomy and that the liabilities in case of accidents will rely on the AV and the surrounding infrastructure, the user of the system is considered just like passengers. Moreover, it is considered that the user does not have any liabilities in case of accidents and the transport provider should take care of the insurance of their passengers. By doing so, the user is always protected during the trajectory of the trip while the user is inside the vehicle.

5.5. Conclusions

In this chapter, question III is answered: *What does a BC-enabled MaaS system architecture look like?* This is achieved by looking into the requirements of the system and evaluating the design alternatives and components for the BC architecture proposed by the ontology of Tasca et al., (2017). By doing so, an overall view of the BC architecture is presented in *Figure 5* as the initial step to demonstrate the design decisions taken in this chapter. This chapter is used as input for the next chapter to demonstrate how the business process and reference architecture of the system would look like.

6. System demonstration

In this chapter, the fourth phase of this research is conducted and question IV is answered: *How to demonstrate the business processes and reference architecture of such concept design look like?* Moreover, the design decisions and sketches created in the previous chapter are further explored. To achieve this, a walk-through process is created to demonstrate the design decisions are reflected in the artefacts functions and structures. This process is done via a BPMN model of the functions of the system and an ArchiMate model of the structure of such a system at a high-level. The AV trip hiring scenario presented in 4.2.1 is further explored and detailed to demonstrate the system and be able to show a walk-through of the design to evaluate the system in the next chapter.

The system demonstration is used to show the artefact feasibility and consists of descriptive and explanatory knowledge by explaining how and why the artefacts work in a particular situation (Johannesson & Perjons, 2014). To demonstrate and communicate the idea of the artefacts a case scenario is detailed aided with a visual representation of the system functions and structures. It is relevant to mention that for simplicity purposes and to develop a clean BPMN model an accident is not considered in this case scenario. In this sense, the insurance provider does not form part of the business processes that are modeled below.

The business processes are written and visualized with a BMPN model utilizing the software Microsoft Visio. Furthermore, to have a high-level perspective of the system structure the modeling software Archi is used to represent the reference architecture of a BC-based MaaS system with the adoption of AVs.

The following case scenario is considered as the guide to walk-through the system and demonstrates it:

A person (User) needs to realize a trip from point A to point B. The user wants to do a trip in a BC-enabled MaaS system that use AVs as a means of transport. This user creates an account in such a system. Following this, the user makes use of a smart device to order the trip to get to a destination. The user enters the travel needs, then the platform shows the available routes, prices, and vehicles for such trips which are validated via a BC network. The user selects the desired route according to their preferences and the AV is reserved for the user trip. Further, the user gets a ticket on a wearable device showing the AV information and characteristic, then waits for the AV to get to the starting point at A. When the vehicle arrives at the pickup location, the user receives a notification in a wearable device that notifies that the vehicle is there. Consequently, the AV recognizes the user ID and opens its doors. Eventually, the trip is started and the user is offered additional services like music, movies, or Wi-Fi access. In this case, the user decides to watch a movie during the trip. Next, the user gets to the destination at point B. Consequently, the user and the AV finish the trip in the system and the user is charged according to the actual use of the vehicle and the watched movie. Then the services are validated in a BC network and paid by the user via a Smart Contract.

6.1. Business processes

The Business Process Model Notation (BPMN) is a standard notation that is used by the business analyst to draft a process, the technical developer to implement the technology involved in that process, and the business user that will control and monitor such processes (Object Management Group, 2011). This is useful to provide a standard communication means for each of the previously described actors to design and implement a process. In addition to this, it also helps to capture and describe the functional behavior of requirements (Rocha & Ducasse, 2018).

BPMN can also provide readability and flexibility of flowchart notations. In this regard BPMN provides communication to a variety of users, allowing them to easily differentiate between sections in a BPMN diagram. They are basically formed by three different types of sub-models and five categories of elements.

BPMN sub-models:

1. *Processes:* This could be private executable or non-executable processes that are internal to a determinate organization. It could also be public processes that represent the interaction between private business processes and others.
2. *Choreographies:* This represents the expected behavior between the relating entities.
3. *Collaborations:* This will represent the interaction between two or more entities.

Categories of elements:

1. Flow Objects
2. Data
3. Connecting Objects
4. Swim lanes
5. Artifacts

To demonstrate the business processes of the system the main functions of the system are detailed and visualized in a BPMN model. This is achieved by looking into the user scenario described in 4.2.1 and considering the BC architecture components described before. The first function starts with the user creating an account and an ID. Then the user can retrieve information from the system about journal planning followed by the ability to book the desired route. In addition to this, the user also has access to payment systems, via smart contracts, for the selected services. Finally, the user interacts with the ticketing system to gain access to the AV. The system functions are grouped in: Account creation, Planning and Booking, Ticketing, and Payment.

6.1.1. Account creation

This is the first process that the system needs to perform to allow the user to have access to the system and be recognized via a unique ID for the transactions that the user will use in the system. As stated before, for security, privacy, and GDPR compliance reasons the user identity information is stored off the BC. Instead, the data provider is in charge of storing this information securely and the MaaS provider handles the inquiry for account creations. Furthermore, the process starts with a request from the user to create an account, the MaaS provider creates a request to create such an account followed by the account information storage the data provider. The process ends when the user receives a confirmation email from the MaaS provider and gains access to the system, as illustrated in *Figure 6*.

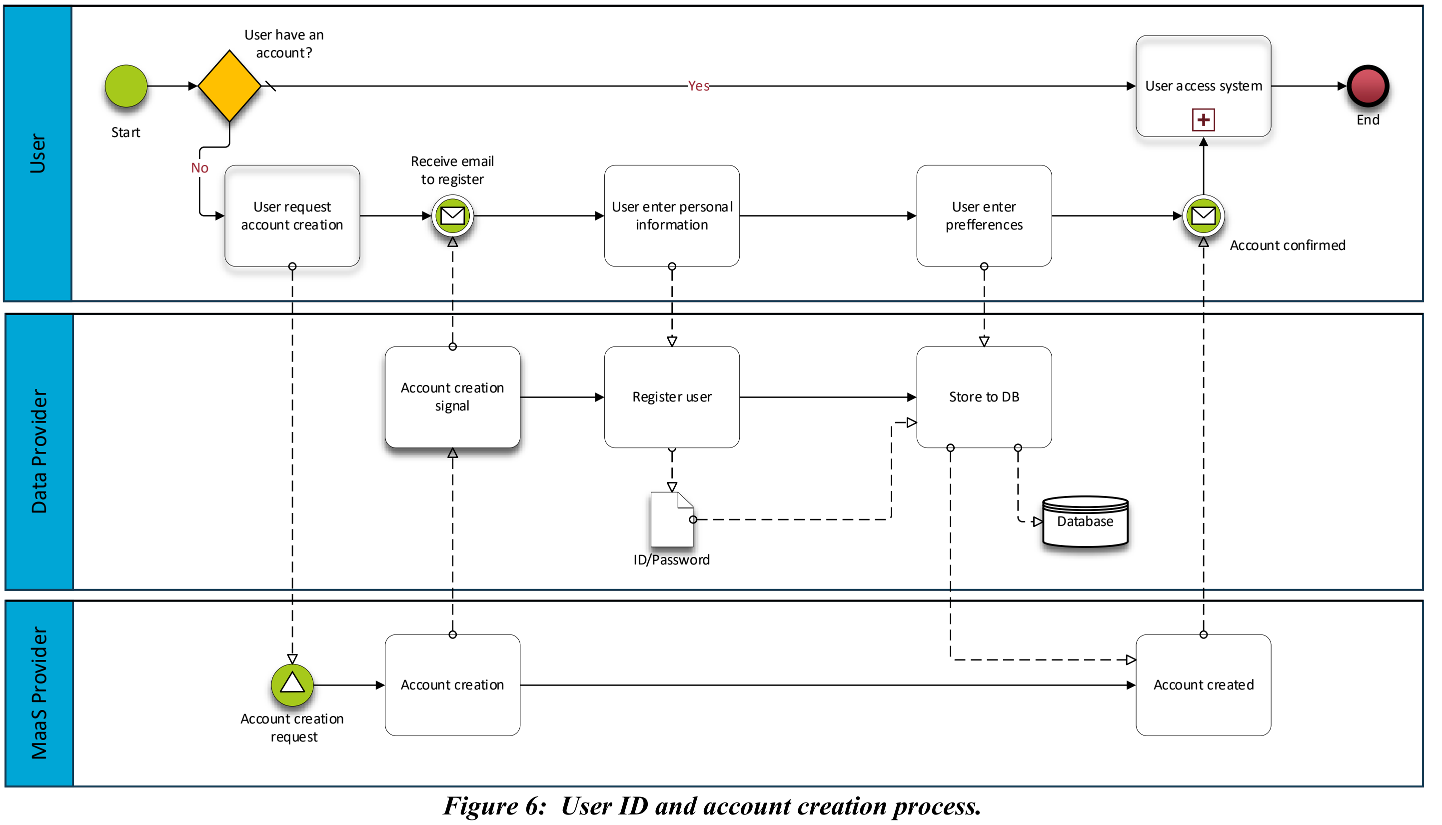

Figure 6: User ID and account creation process.

6.1.2. Planning and Booking

The second process is a combination of two functions that are closely related, planning, and booking. In this process, the user requests route information, then the MaaS provider handles this request that is processed via the data provider to reach the transport provider. To fulfill trust, privacy, and security requirements the planning information is validated by the BC network. After this, the user selects the desired route according to his preferences. As a result, the transport provider books and dispatches the AV, the data provider processes the AV information to create the notification task done by the MaaS operator. Finally, the user receives a notification that the AV is on the way to pick him up as illustrated in *Figure 7*.

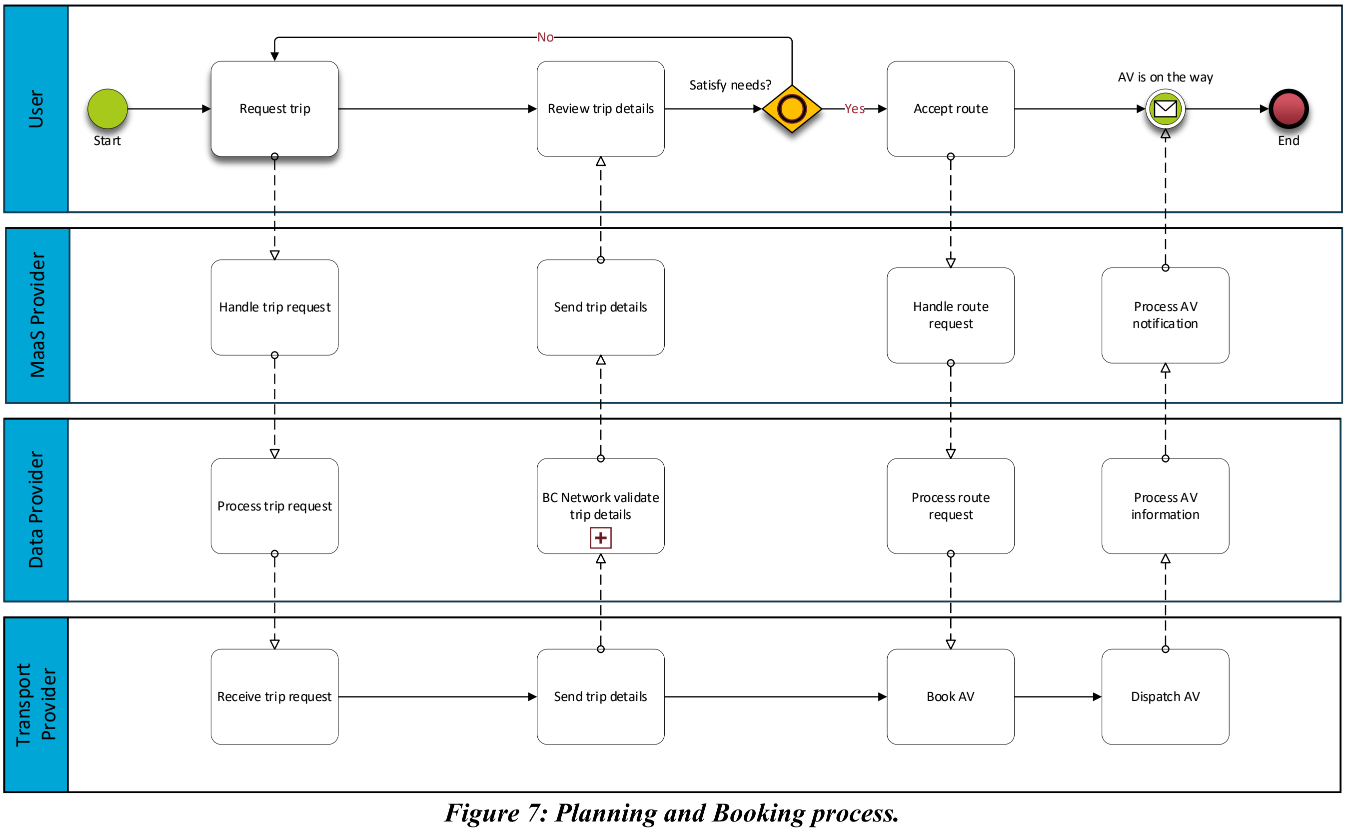

Figure 7: Planning and Booking process.

6.1.3. Ticketing

The third process of the system consists of the creation and emission of a ticket that grants the user access to the AV. This process starts when the AV is dispatched from the transport provider then the data provider processes this information and creates the ticket that is sent to the user via the MaaS provider. Following this, the user receives the ticket and user to gain access to the AV. This access request is validated by the data provider, once the ticket is valid the data provider sends a confirmation to the transport provider which sends a signal to the AV to unlock it. Finally, and how is illustrated in *Figure 8* the user enters the vehicle and the trip starts.

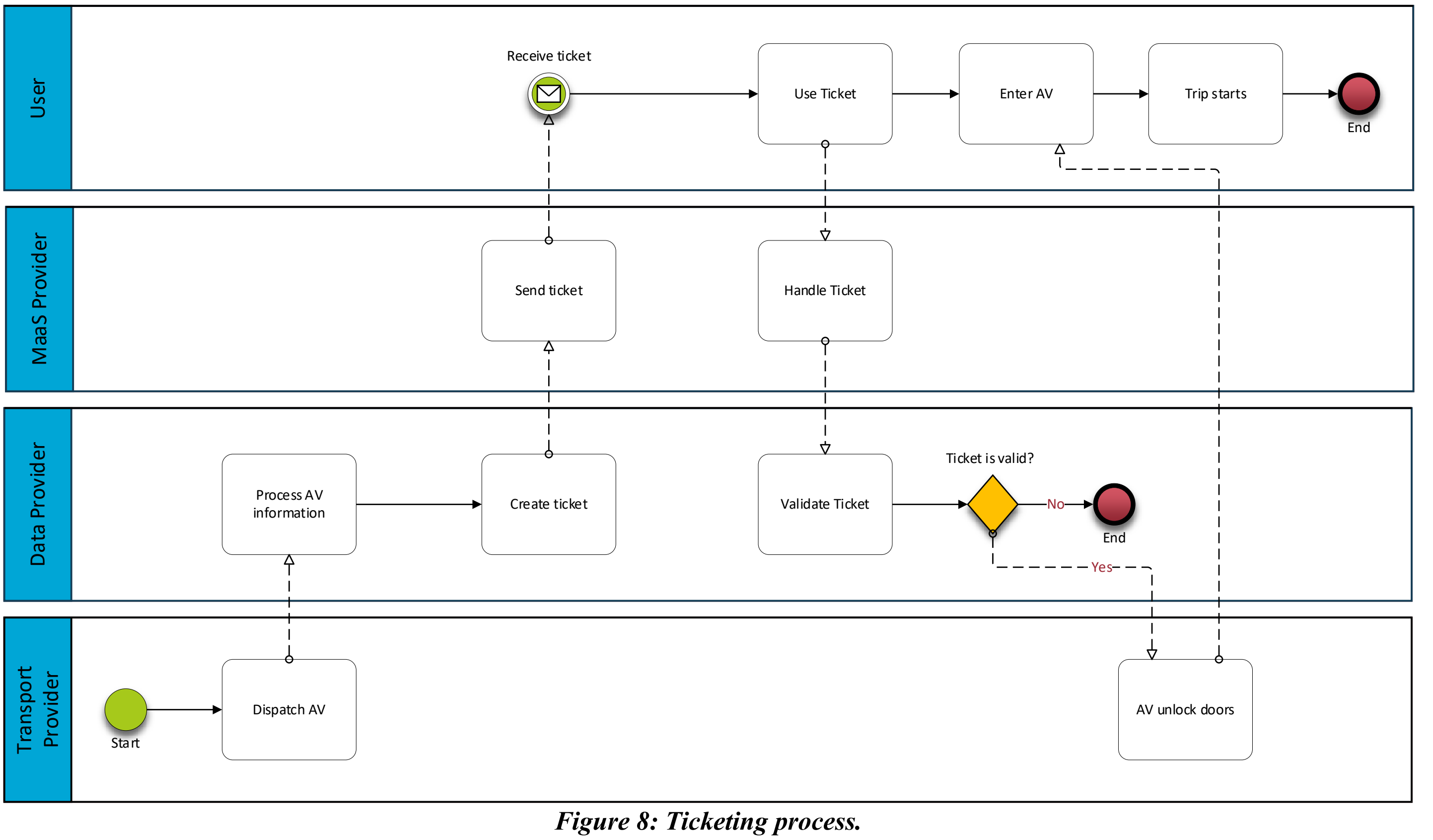

Figure 8: Ticketing process.

6.1.4. Payment

The final process describes the payment for the trip and additional services as illustrated in *Figure 9*. In this process, the MaaS provider handles the starting, services, and ending trip information to the data provider that processes and stores such information. Then the BC network validates these transactions using the pBFT consensus mechanism as described in Chapter 5. This is designed to increase trust, automating payment processing, and avoiding a single point of failure. When these transactions are validated by the BC network the data provider receives a confirmation and the Smart Contract takes care of the transactions automatically by sending a payment request to the user, then processes the payment and finally sends an invoice to the user when the payment is complete.

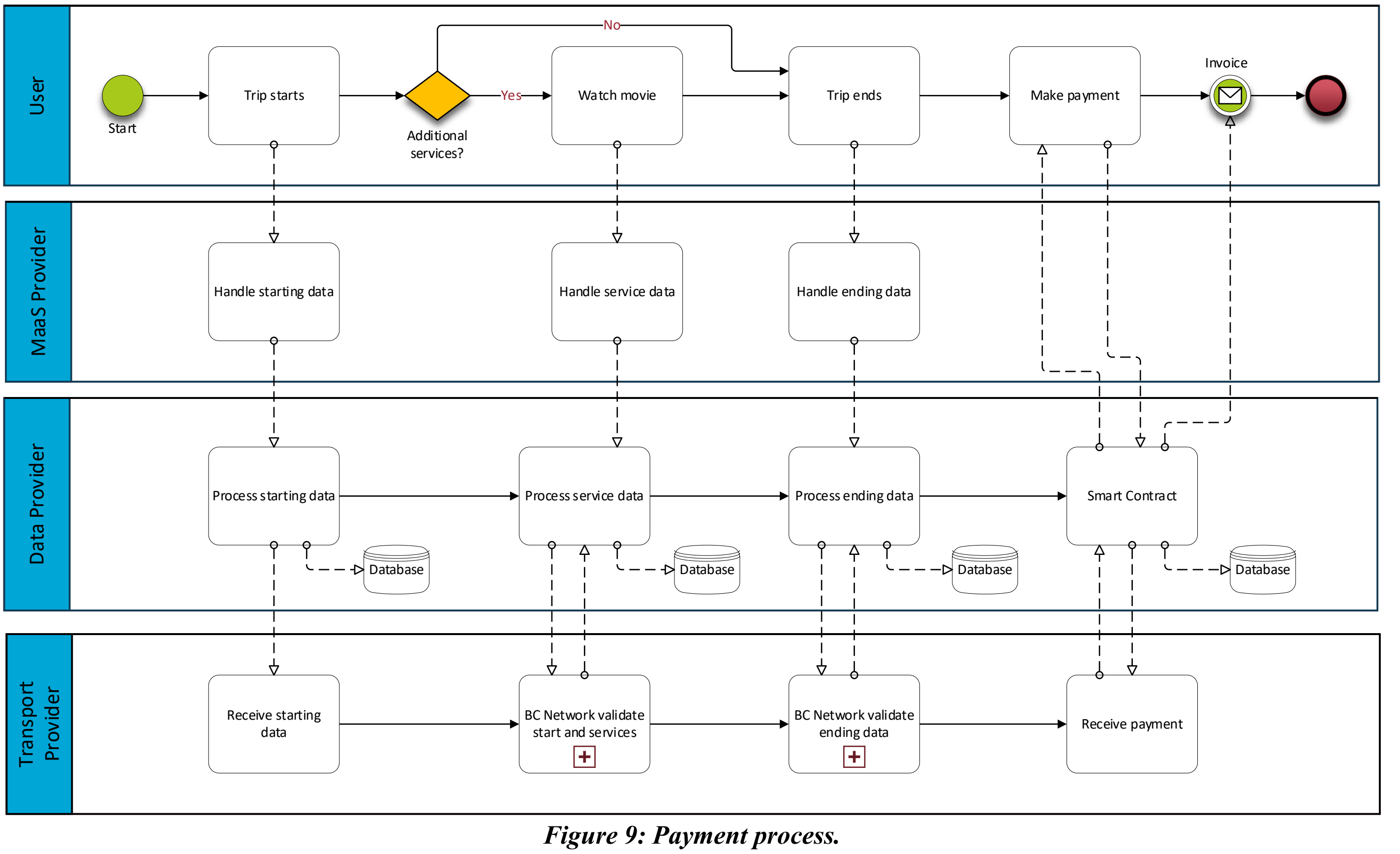

Figure 9: Payment process.

6.2. Reference architecture

Enterprise Architecture (EA) is purposed to define a system composition from a different point of view by reducing the inconsistency from conceptual and implementation design as well as business and ICT sectors (Doucet et al., 2009). Richardson et al, (1990, as cited in Doucet et al., 2009) define EA as the interrelation between data, software, hardware, communication resources, and the required organization to maintain the physical structure needed by the architecture. Furthermore, in Doucet et al., (2009) EA is defined as an abstract description of reality and a frame of reference to design the construction of an artefact which is used to demonstrate this work. In this sense, EA can be used to illustrate design decisions from a description of the elements and interaction of them while safeguarding the management of the dependencies of these elements.

To deal with this complexity a layered approach is used. Stallings (2006, as cited in Doucet et al., 2009) state that a layer model possesses three main characteristics:

1. Layers have a related set of functions.
2. Lower layers provide services to higher layers
3. Layers should allow changes in other layers without affecting them.

To describe an EA a modeling language is used. For this work, ArchiMate is selected as a language tool for modeling the EA proposed. Moreover, ArchiMate is a visual language with a determinate iconography to analyze, describe, and communicate elements of an EA. This tool provides a standard with a set of entities and relationships with the matching iconography to represent the EA (The Open Group, 2018). In this regard, ArchiMate is a graphical notation used to model architecture concepts and describe them. This is done by using a layered approach that divides the EA into three main different layers:

1. *Business layer:* These are the products and services offered by business actors and roles.
2. *Application layer:* This layer supports the business layer with application components.

3. *Technology layer:* This supports the application layer by providing the infrastructural services needed for the applications.

To demonstrate the architecture of the proposed system a reference architecture model is developed to serve as a general design of the structure of a BC-based MaaS system with the adoption of AVs. This high-level model is used as a way to untangle the complexity of the system and show how the components of this specific system are structured. Furthermore, this reference architecture model could be used as a blueprint for future research and development to create the enterprise architecture of similar systems. For this research, the Business, Application, and Technology Layers of the reference architecture of a BC-based MaaS system with the adoption of AVs is explored. Furthermore, the functions of the system are supported by the technology and application layers of the representation. In these layers, an application server is illustrated to host the application and a distributed ledger is pointed to support the BC architecture of the system. Both the technology and application layers are needed to support the services and processes of the business layer.

The process of design and develop an artefacts is usually done by adapting and reusing elements of existing solutions and creating new components with novel combinations (Johannesson & Perjons, 2014). While BC reference architecture is a novel topic the work of Schindewolf, (2018), Spijkerboer, (2019), Mishra & Sil, (2019), Husak et al., (2015) and Viswanathan et al., (2019) are used to analyzing current BC architectures related to mobility solutions and adapt them to fit the design objectives of this work. By doing so, the following BC-based MaaS with AV reference architecture is proposed in *Figure 10*.

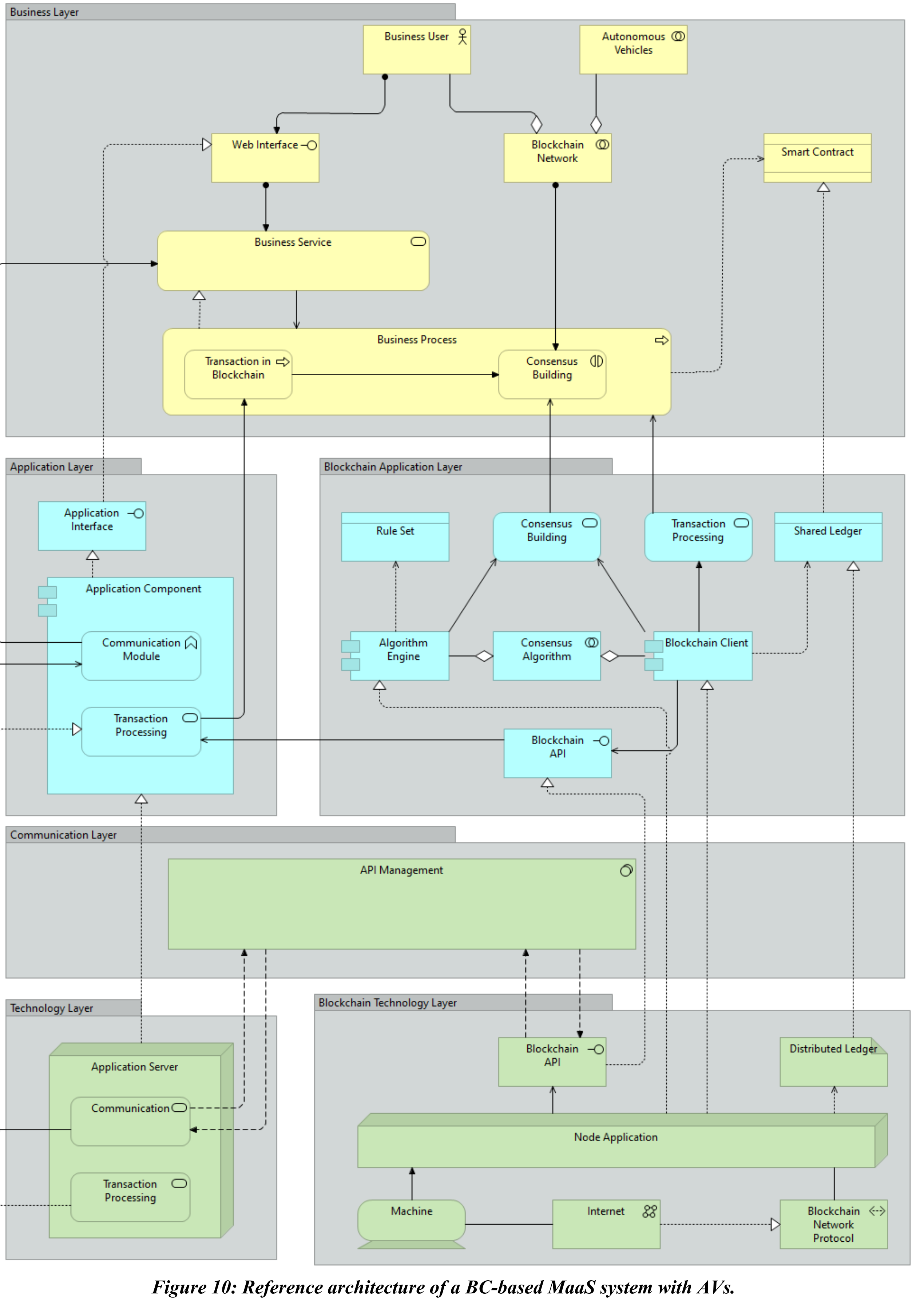

Figure 10: Reference architecture of a BC-based MaaS system with AVs.

6.2.1. Business Layer

The business layer illustrated in *Figure 11* shows the services that the system offers supported by the business processes that the system performs. On top of the business layers are the actors that participate in the system. These actors are mainly the user of the system and the AVs that participate in the BC network of the system to offer computational power to validate transactions. The business user interacts with the system via a web interface that gives the user access to the services offered by the system. These services are powered by the business process of the system that handles the transactions which are submitted to the BC, this generates the consensus-building process that is later validated in the BC network to create a Smart Contract for the payment of such transactions.

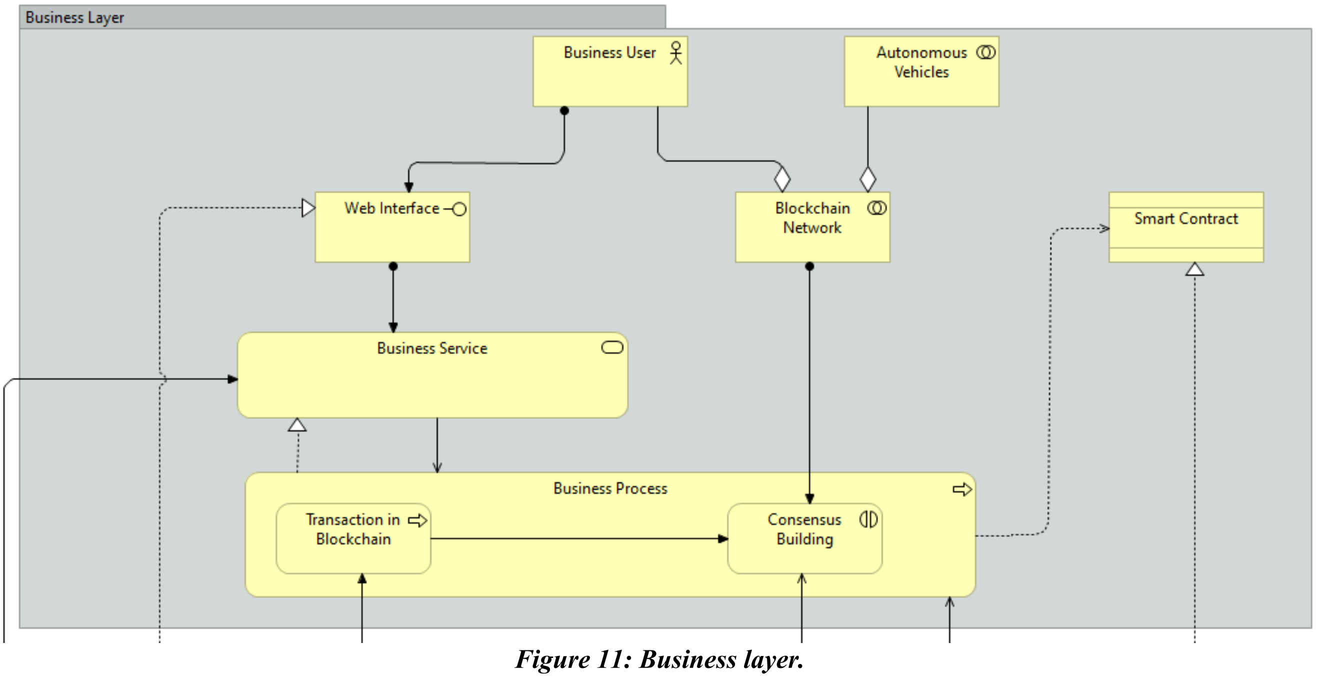

Figure 11: Business layer.

6.2.2. Application Layer

The application layer is formed by two groups, the application layer and the BC layer as showed in *Figure 12*. In the application layer, the software components that support the business layer are illustrated. Furthermore, the application layer is formed by an application interface and an application component. The application interface interacts with the web interface in the business layer to enable the user for its interaction with the system. In addition to this, the application component is formed by a communication module and transaction processing. The communication module is in charge of handling information to the business services in the business layer and communicate with other integrated systems. Moreover, transaction processing is in charge of processing the transaction to the BC.

The application components of the BC are illustrated in the BC application layer group. This layer is enabled by the BC nodes in the technology layer. Furthermore, it is formed by a BC client that handles the processing of the transactions via the BC API and with the consensus algorithm participates in the consensus-building of the system. In addition to this, the BC client also accesses the shared ledger to participate in the creation of the smart contracts. Moreover, the algorithm engine is also participating in the consensus-building with the consensus algorithm ruled by the rule set.

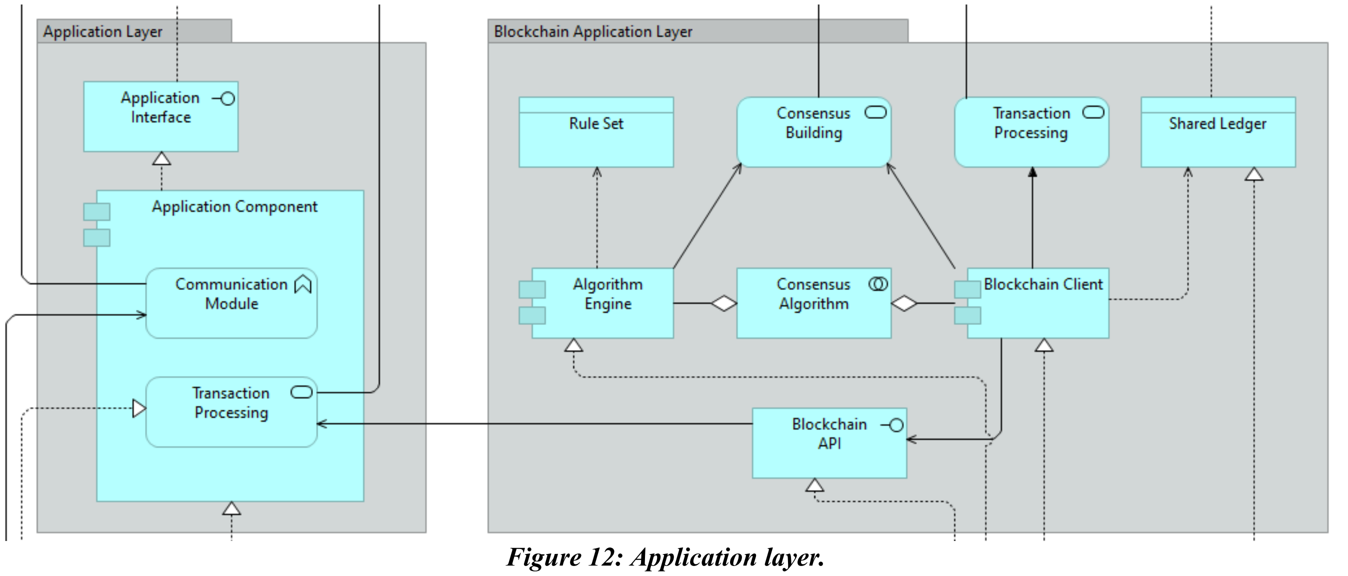

Figure 12: Application layer.

6.2.3. Technology Layer

Finally, the technology layer illustrated in *Figure 13* is formed by three groups, a communication layer, the technology layer, and the BC technology layer. The technology layer is in charge of the infrastructure needed to run the applications in the system. The communication layer group act as the intermediary for translating messages among different services via the API management and handles the communication between the BC and the application. The technology layer group is formed by the application server that hosts the application component in the application layer. This enables the communication and transaction processing of such an application component. Finally, the BC technology layer represents the actors that form part of the BC network, mainly the users and the AVs. These actors participate in the node application via a virtual machine to offer more freedom to run the BC application. This virtual machine has access to the internet ruled by the BC network protocol mentioned in chapter 5. The node application interacts with other systems via a BC API that is handled by the communication layer. The BC database is formed by the participant nodes that creates a distributed ledger.

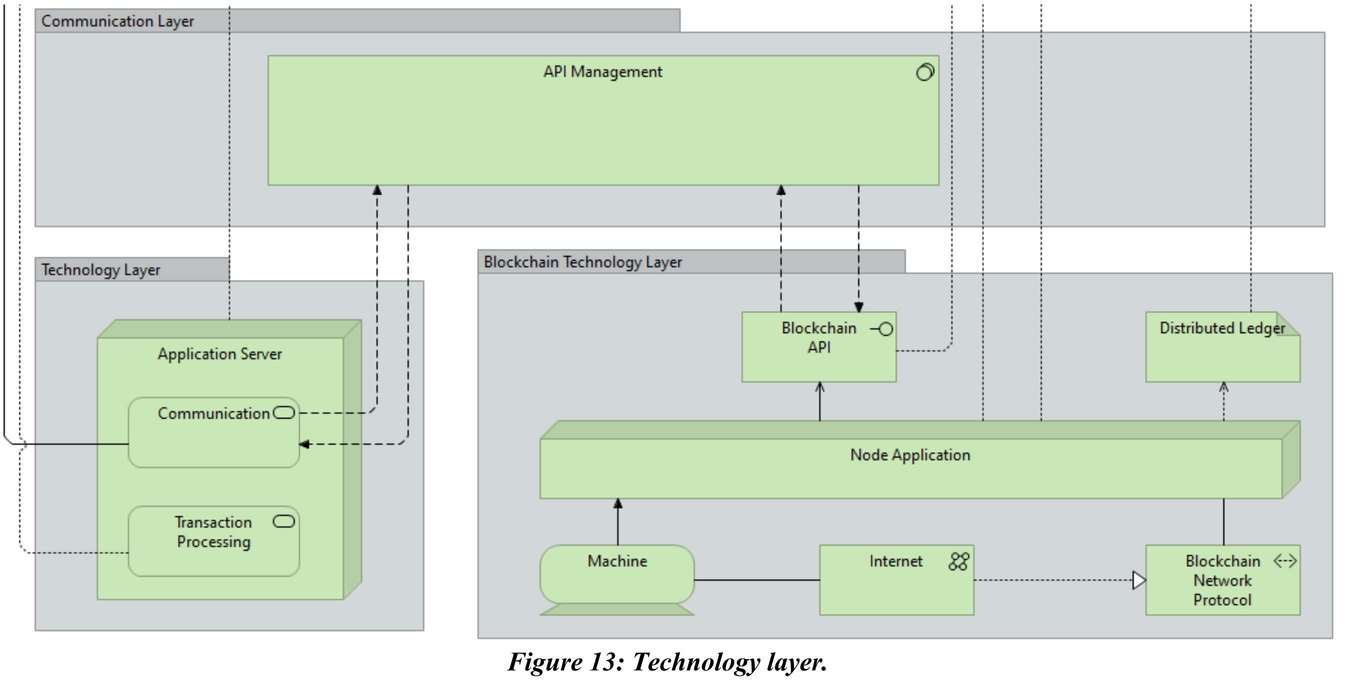

Figure 13: Technology layer.

6.3. Conclusions

In this chapter question IV is answered: *Which business processes and reference architecture could support the design of the BC-enabled MaaS concept system with the adoption of AVs?* This is achieved by the illustration of the business processes via BPMN models of the system to explore the main functions offered by the system. These main functions are Account creation, Planning and Booking, Ticketing, and Payment. In addition to this, the system structures are presented via an ArchiMate models that represents how a BC-enabled MaaS concept system with the adoption of AVs looks like. These systems structured are represented in the Business layer, Application layer, and Technology layer. In this chapter, it is possible to demonstrate how a BC-enable MaaS concept system with the adoption of AVs looks like. The objective of this chapter is to learn how to demonstrate the design decisions taken in *Chapter 5* to then evaluate such decisions, processes, and requirements with a semi-structured interview process that is conducted in the next chapter.

7. System evaluation

In this chapter, the fifth phase of this work is done and the question V of this research is answered; *How to evaluate the BC-enabled MaaS concept system with the adoption of AVs?* The objective of this chapter is to evaluate the validity of this research process, the fulfillment of the requirements, and the ability of the artefact to explore the realization of a BC-enable MaaS concept system with the adoption of AVs. To do this, an evaluation plan and semi-structured interview process is explained in 7.1 were the objective, means, and relationship between them are assessed from a group of experts guided by a walking-trough semi-structured interview to determine the quality of the proposed concept design and answering sub-question *a*. Furthermore, the group of experts and their feedback inputs are evaluated in sections 7.2 and the proposed correction in section 7.3 to answer sub-question *b*. Finally, the conclusions of this chapter are presented in section 7.4 to assess the accomplishment of the objective of this research by answering sub-question *c*.

7.1. Evaluation plan

The main goal of the evaluation process is to determine if the proposed artefacts are useful and live up to the expectation of exploring how a BC-based MaaS system with the adoption of AVs would look like, their most primary systems, requirements, and configurations. For this, a formative evaluation is conducted that assesses the design process of the proposed artefacts (Johannesson & Perjons, 2014).

The means for doing this are a set of semi-structured interviews that are formed by a group of experts via flexible open questions that can be discussed and allows the interviewees to respond to them in their own words (Johannesson & Perjons, 2014). In this regard, the design requirements and assumptions are treated as sub-objectives needed to achieve the design objective, which is reflected in the structural specifications of this design (Verschuren & Hartog, 2005). This is an ex-ante evaluation; this means that the evaluation is conducted to assure that the design process is correct and the resulting design will not fail (Verschuren & Hartog, 2005). Moreover, an ex-ante evaluation can be done faster, does not require a large number of resources, users or organizations and it is ideal to evaluate an initial design or porotype (Johannesson & Perjons, 2014).

To evaluate the process and the results of this research thesis, at least one question is formulated to evaluate each of the presented chapters. The main objectives of this last phase of the DSR are to evaluate if the process is well done and if it makes sense to the evaluators. In addition to this, in this phase, the reliability, verifiability, and validity of the research are evaluated. By doing so, the questions presented in *Table 9* are formulated considering the aforementioned evaluation plan and the relation between the goals and means of this research.

#	Question	Purpose
1	Could you state if the **research methodology** is valid for the intention and objective of this research?	Check validity, reliability, and verifiability of the research.
2	Could you state if the defined **design requirements** are operationally defined?	See if requirements cover exogenous requirements while matching the design goals.
3	In your opinion: does the **design assumptions** make sense in the context of this research?	To check the credibility and acceptance of the assumptions made.
4	In your opinion: are the **design requirements** reflected on the **BC architecture** design decisions?	To assess the quality of the conversion of design requirements into the structure of the BC design.
5	In your opinion: is the **BC architecture** aligned with the **design decisions**?	To ensure that the structural specifications are reflected in the prototype.

6	In your opinion: are the **design objectives**, **criteria,** and **assumptions** reflected in the **designed artefacts**?	Assess the process and outcome of the implementation in the artefacts.
7	To what extent do you think that the **objectives** of this research are achieved?	Assess to what extent the goals of this research are fulfilled
8	Do you see any other **objectives** that could be achieved by this research?	Future research topics and recommendations.

Table 9: Semi-structured questions.

7.2. Expert evaluation

The expert evaluation was conducted with a semi-structured interview by a walk-through with experts in Blockchain, ICT architectures, and autonomous systems. The names, background, affiliation, date, and setting of these interviews is available in *Table 10*. A walk-through is an evaluation instrument similar to a peer review were the designer leads the expert's trough a method or artefacts (Johannesson & Perjons, 2014). In this style of interviews, the experts are allowed to ask questions, identify problems, suggest other solutions, or give any other kind of feedback (Johannesson & Perjons, 2014).

The interviews were conducted via telecommunication applications like Skype or Zoom, they had a duration of approximately one hour each. Furthermore, these semi-structured interviews were conducted in the English language and recorded for further analysis. An interview consent form was signed by the interviews to fulfill GDPR requirements which can be found in *Appendix C*. Moreover, transcription tables are provided in the same appendix for each of the interviewed experts.

Table 10: Group of experts.

Name	Background	Affiliation	Date	Setting
Dr. Sélinde van Engelenburg	Business-to-government Information sharing using Blockchain technology.	Researcher at TUDelft.	10/08/2020	Skype call
Prof.dr.ir. Marijn Janssen	Full professor in ICT & Governance. ICT-architecting in public and private organizations where collaboration is needed.	Professor at TUDelft. Head of the ICT section of the Technology, Policy, and Management faculty at TUDelft. Antoni van Leeuwenhoek chair in "ICT and Governance".	14/08/2020	Skype call
Patrick Fahim MSc.	Maritime freight systems and also autonomous freight, autonomous vehicles in logistics. Also, data platforms and information platforms in freights.	Ph.D. candidate at TUDelft.	17/08/2020	Zoom call

7.3. Corrections

In this section, the evaluation from the group of experts semi-structured interviews are conducted by analyzing the recorded audio files and summarizing the most relevant aspect of the answers in *Appendix C*. Moreover, an overview of the main issues found in the interviews and how is addressed to include the feedback into the design of the artefacts is presented in *Table 11*.

Table 11: Feedback overview.

Feedback Overview	How to address it.
Some of the GDPR requirements like U7 might not be fully achieved in this research. For example, there is a need for goal-binding of the personal information. It is very hard to establish the exact requirements without the help of a juridical expert.	Further analysis is conducted regarding Article 5 of the GDPR regulations with a correction of the GDPR requirements presented in *Table 12*. In this table, four new GDPR requirements were added. Regarding the full implementation for the GDPR, it is something valuable to consider but it escapes the scope and time limitations of this research. In addition to this, it is not possible at this stage and due to time limitations to consider the help of a juridical expert to fully validate GDPR compliance. Nevertheless, this could be a good addition to future research.
Encrypting the data is not enough to protect it according to GDPR and even hashing it might not be enough.	While data encryption and protection are really important topics in this design, it is also not the field of expertise of the researcher. Moreover, a very detailed description of data protection and encryption does not fit with the high-level proof of concept design of this work.
One of the requirements is scalability and it does not appear that scalability, maybe a stress test is needed. This is the same for some security requirements.	It is quite hard to perform a stress test of the requirements, while it is relevant that all the requirements are fulfilled by the design it is also relevant to mention that in this high-level proof of concept design it is not possible to implement such a system due to technical limitations. Level 5 of the autonomy of the AV and 5G network are not yet developed. Besides, security requirements details are not the expertise nor the intention of this research.
The business process artefact and scenario does not include the process of canceling a trip as mentioned in the requirements.	Develop a new BPMN model with the cancelation of the trip included process included. This is illustrated in *Figure 14* followed by the corrected case scenario.

Some of the missing requirements identified in the system evaluation regarding GDPR and the article 5.

Table 12: GDPR requirements correction.

ID	Source	Requirement	Justification
U7	*Institutional*	The system shall comply with GDPR regulations.	Data protection regulations.
S7.1	Institutional	The system must consider privacy by design.	User data could be sensitive and should comply with GDPR.
S7.2	Institutional	The system must consider data minimization and purpose limitation regarding user data.	GDPR principles for processing personal data.
S7.3	Institutional	The system must notify the user if personal data is a breach.	GDPR breach notification compliance.

S7.4	Institutional	The system must allow the user to access his personal data.	GDPR right of access compliance.
S7.5	Institutional	The system must allow the user to delete his data.	GDPR right to erasure compliance.
S7.6	Institutional	The system must ask for consent for data gathering and processing.	GDPR affirmative consent compliance.
S7.7	Institutional	The system must process data lawfully, fairly and in a transparent manner.	GDPR data processing compliance.
S7.8	Institutional	The system must maintain user data accurate and up to date.	GDPR data accuracy compliance.
S7.9	Institutional	The system must keep user data no longer than it is necessary.	GDPR storage limitation compliance.
S7.10	Institutional	The system must process data in a secure way and protect it against unauthorized processing, accidental loss, destruction, or damage.	GDPR integrity and confidentiality compliance.

The correction to the BMPN model of the planning and booking process is about the option to cancel a trip. This is included at the end of the process with a question prompted to user which can result in a premature cancellation of the trip.

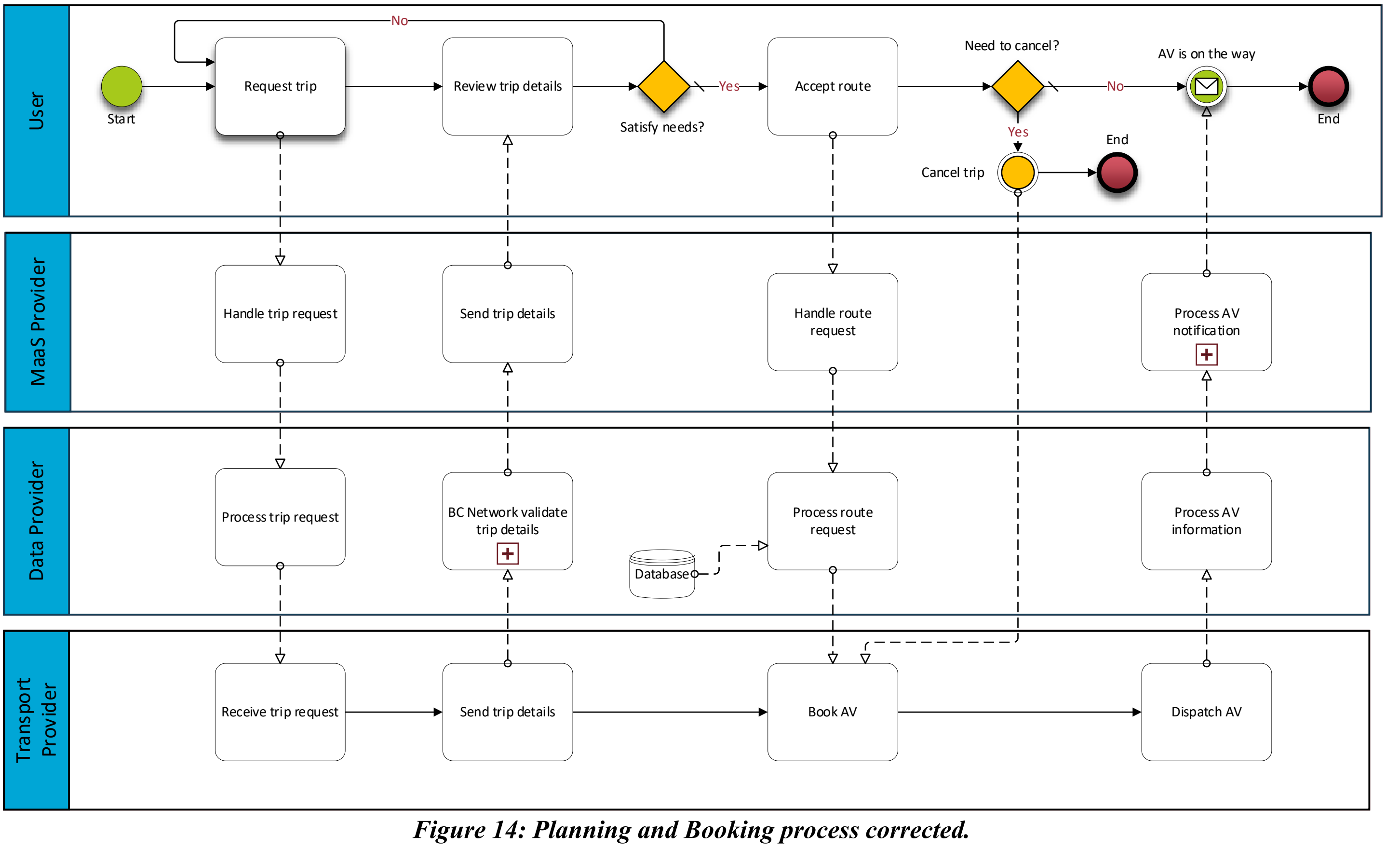

Figure 14: Planning and Booking process corrected.

Corrected case scenario

A person (User) needs to realize a trip from point A to point B. The user wants to do a trip in a BC-enabled MaaS system that use AVs as a means of transport. This user creates an account in such a system. Following this, the user makes use of a smart device to order the trip to get to a destination. The user enters the travel needs, then the platform shows the available routes, prices, and vehicles for such trips which are validated via a BC network. The user selects the desired route according to their preferences and the AV is reserved for the user trip. The user has the option to cancel the trip before it is started. Further, the user gets a ticket on a wearable device showing the AV information and characteristic, then waits for the AV to get to the starting point at A. When the vehicle arrives at the pickup location, the user receives a notification in a wearable device that notifies that the vehicle is there. Consequently, the AV recognizes the user ID and opens its doors. Eventually, the trip is started and the user is offered additional services like music, movies, or Wi-Fi access. In this case, the user decides to watch a movie during the trip. Next, the user gets to the destination at point B. Consequently, the user and the AV finish the trip in the system and the user is charged according to the actual use of the vehicle and the watched movie. Then the services are validated in a BC network and paid by the user via a Smart Contract.

7.4. Conclusions

In this chapter question V is answered: *How to evaluate the BC-enabled MaaS concept system with the adoption of AVs?* This is achieved by the realization of a semi-structured interview guiding a group of experts by a walking-trough process. These interviews resulted in various improvements regarding the fulfillment of the requirements of this master thesis research. While the feedback provided by a group of experts is relevant and important for the design of a BC-based MaaS concept with the utilization of AVs it is not possible to include them all due to time and scope limitation of this research. Moreover, some of the presented feedback gave great insight into possible future research topics and improvements. In general, the group of experts was pleased about the design methodology used for this research as well as the designed artefact and the accomplishment of the research objective. The inputs generated in this chapter enable the conclusion and discussion of this research that are presented in the final chapter of this research.

8. Conclusions and reflection

In this last chapter of this research results from each of the previous chapters are derived to answer the main question: *How might a Blockchain-based Mobility-as-a-Service system with the adoption of Autonomous Vehicles concept design look?* For this, a conclusion from each of the previous chapters are presented in section 8.1 by answering each of the sub-questions of this research. Next, the scientific relevance of this research is discussed in section 8.2. Furthermore, societal relevance is also considered in section 8.3. After this, a reflection is presented in section 8.4 were the limitations and possible future research topics are discussed. Finally, a link between this research thesis and the CoSEM programme is made in section 8.5.

8.1. Conclusions

The main objective of this research is to explore what a Blockchain-based Mobility-as-a-Service concept design with the adoption of Autonomous Vehicles would look like, their most elemental systems, requirements, and possible configurations. To achieve this objective a Design Science Research approach and a systems engineering perspective are used with the intention to answer the main research question:

How might a Blockchain-based Mobility-as-a-Service system with the adoption of Autonomous Vehicles concept design look?

To answer this main research question five sub-question was proposed to gain adequate knowledge to answer the main research question. The first sub-question of this research is:

I. *How would a MaaS system based on AVs look?*

To answer this question a literature review and desk research was conducted. To further answers this question a system engineering approach is taken to analyses the technical and institutional subsystems and the relevant stakeholders. Moreover, this led to other follow up sub-questions: *What does a technical sub-system look like?* To answer this question a technical analysis of the MaaS system was conducted. In this analysis, a definition of MaaS is provided. Moreover, it was found that the MaaS system is composed of core characteristics that are supported by some key functionalities that the system must offer. In this regard, these are; ***User identification, Planning, Booking, Access to real-time information, Payment,*** and ***Ticketing.*** These are considered as the minimum elements needed to support the transactions of a MaaS system.

Next, the institutional sub-system is studied to answer the following question: *What does an institutional sub-system look like?* To answer this question an institutional analysis of the system is conducted. In this regard, is found that the MaaS system relies on personal data, and regulations like GDPR could have an impact on the design of such a system. Moreover, elements like Privacy by Design, Consent, and Protection must be considering to implement this system in Europe. For this, an overview of the GDPR articles is presented with the intention of aligning the design of the artefacts with GDPR regulations. The main GDPR articles that affect such a system are ***Articles 5, 7, 15, 17, 25, 34, 37, 38, 39.***

Finally, the relevant stakeholders that would take part in op this system design are discussed with the following question: *Which relevant stakeholders could form part of a MaaS system based on AVs?* To answer this question a description of their interest, relationships, resources, and roles is discussed. Later, is found that a MaaS system is composed of a ***MaaS provider, Transport provider, Data provider, Insurance provider,*** and ***the user.*** By answering this follow-up sub-question is possible to have a description of the system and their corresponding sub-systems which are used as input for the next sub-question.

II. What are the requirements needed for a MaaS system based on AVs?

This second sub-question is done by identifying the main requirements of the system. These requirements are gathered via desk research based on requirements engineering and system process with the input of the previous chapter. From these requirements, it is possible to develop the BC architecture, business processes, and reference architecture artefacts proposed in this research. The constrains and user and system requirements can be found in *Table 5*, *Table 6,* and *Table 7*. These requirements are used as the foundation for the design of the artefacts proposed in this research and are used in the next phase which leads to the third sub-question. In this chapter it is found that the dominating requirements of the systems are about ***Latency, Transparency, Privacy*** and ***Security.***

III. How does a BC-enabled MaaS with the adoption of AVs system architecture look?

This third sub-question is answered by desk research and literature review on BC architectures. To start this process another follow-up question is required:
What are the design options to consider? To answer this question the possible BC architecture elements are considered as well as the sub-elements. These elements are studied and according to the requirements, design decisions were taken so that the chosen elements fulfill the requirements of the system. These are mainly seven components to consider to develop a BC architecture; ***Consensus mechanism, Transaction capabilities, Native currency/Tokenization, Extensibility, Security and Privacy, Identity Management, Charging,*** and ***Rewarding system.***

To assess these components the next question was proposed: *How does the architecture fit the requirements?* To answer this question the requirements of the previous phase were carefully analyzed and compared to the components and chosen to best fit the requirements. Moreover, an overview of the design decision and its requirements are presented in *Table 8.* In addition to this, a sketch of the BC architecture is presented in ***Figure 5***. By answering question III is possible to see how the BC architecture of a BC-based MaaS concept system with the adoption of AVs look like. It is also relevant to mention that the most decisive elements in designing the BC architecture for this system are related to ***Latency*** and ***Security***.

IV. Which business processes and reference architecture could support the design of the BC-enabled MaaS concept system with the adoption of AVs?

This fourth sub-question is answered by developing two artefacts. The first artefact is created with a proposed case scenario to demonstrate the business processes that the system must perform. This is done by proposing the business processes illustrated with a BPMN modeling tool. With the intention of providing a clear overview of the processes they are separated into four main sub-processes; ***Account creation, Planning and Booking, Ticketing, and Payment.*** Moreover, the BPMN model of these sub-processes are illustrated in ***Figure 6***, **Figure 7**, ***Figure 8***, and ***Figure 9*** respectively. It is concluded that these are the main business processes that are needed for the system.

In addition to this, a reference architecture is created to represent the design of the structure of a BC-based MaaS system with the adoption of AVs. Moreover, the Business, Application, and Technology layers are presented with their most elemental structure and components. This is done to have an overview of the system structure and further illustrate how the proposed system would look like. The overall reference architecture of the system is exhibited in ***Figure 10*** with the technology and application layers needed to support the services and processes of the business layer. By doing so, it is possible to have an overview of how a BC-based MaaS concept system with the adoption of AVs look like. Following this, the final phase is conducted to evaluate this design, for this the next question is proposed:

V. How to evaluate the BC-enabled MaaS concept system with the adoption of AVs?

This fifth and final phase of this research is conducted with the intention to evaluate the proposed system. The main objectives of this phase are to evaluate the process of this research if the requirements are reflected in the artefacts and the achievement of the research objective. For this, three follow-up sub-questions are created.

How to evaluate the process of this research? To evaluate the process, a group of experts was interviewed. This interview is done via a semi-structured interview process guided by a walking-trough with the experts in the technologies used in this research. This resulted in ***positive feedback*** from the experts regarding the use of ***Design Science Research*** approach to create the design artefacts for this research.

Next, to assess the requirements and their impact on the proposed artefacts the following question is answered: *How to evaluate the design requirements and its reflection on the artefacts?* By doing the semi-structured interview it is possible to ask more freely to the expert what is their opinion on the requirements and their reflection in the artefacts. In this part, feedback is considered regarding the GDPR requirements, and an improved version is presented in ***Table 12***. In addition to this, a correction of the Planning and Booking business process is illustrated in the BPMN model of ***Figure 14***. Furthermore, it is also relevant to mention that due to the scope and time limitations of this research is not possible to include all the feedback taken but it is considered for possible future research.

Finally, to assess the accomplishment of the research objective the next follow-up sub-question is answered: *How to evaluate the objective proposed in this research?* To answer this question, the interviewers were asked if they think that the objective of this research was achieved. In this regard, the objective of this research was to explore what a Blockchain-based Mobility-as-a-Service concept design with the adoption of Autonomous Vehicles would look like, their most elemental systems, requirements, and possible configurations. Moreover, the reaction from the interview was positive and in their opinion ***is indeed possible to explore how a system like the proposed in this research looks like with this research***.

8.2. Scientific relevance

This research creates a contribution to the scientific knowledge base by exploring how a blockchain-based Mobility as a Service concept system with the adoption of autonomous vehicles would look like. This novel approach combines technologies like Mobility as a Service (MaaS) with Autonomous Vehicles (AV) enabled by blockchain (BC) technologies that at the moment of writing this research it is not present in the literature. By utilizing a design science research (DSR) approach a set of requirements are gathered that can help in the future to implement a system like the concept design proposed in this research. Furthermore, by fulfilling this set of requirements an innovative BC architecture is created specifically to fit a MaaS system that uses AVs as a means of transportation and procuring issues like privacy, security, and trust. In addition to this, the business processes of the proposed system are illustrated through a series of BPMN models and a reference architecture using ArchiMate as an enterprise modeling language standard. By providing such design artefacts it could help in the future to further design and implement a MaaS system that uses AVs based on Blockchain technologies.

8.3. Societal relevance

This research could have multiple contributions to society. By providing a proof of concept design that could lead to an easier and safer implementation of AVs on intelligent transportation systems. Moreover, by facilitating the implementation of AVs technologies that could lead to a reduction of the ecological impact, accidents and a reduction of toxic pollution, greenhouse gases, noise pollution, traffic jams, and mobility disparities with more efficient and effective vehicles. Furthermore, by facilitating the implementation of a BC-based MaaS system with the adoption of AVs could lead to improvements in transport networks, efficient vehicle, and infrastructure utilization while providing an enhanced customer experience. In addition to this, a rapid adoption of AVs in the mobility industry could lead to an increased transport capacity and a reduction in cost for the consumers. Finally, all of this could be possible by implementing such a system in a secure, private, and trusted environment enabled by BC technologies.

8.4. Reflection

This section is created to reflect on this research. The limitations of this research are discussed in section 8.4.1 followed by a reflection on possible future research that could address the limitations is presented in section 8.4.2.

8.4.1. Limitations

In this section, the limitation of this research is discussed to get an idea of how these limitations could have an impact on the methodology and design artefacts of this research.

Methodology and literature reviews.

Regarding the methodology, limitations can be found in the Design Science Research approach used in this research. Moreover, creating novel innovations by relying on existing scientific theories could make this research even more difficult and could lead to delays and deficiencies. Due to the novelty of the topics explored in this research there is a limited number of academic sources available in the literature. For this reason, an exploratory research methods were used for this research. Moreover, the existing knowledge base could be insufficient for design purposes and the researcher have to use their intuition or experiences while designing such a system.

System description.

The objective of this research is focused on designing a complex socio-technical system; therefore, some boundaries are needed. For this, a delineation of the scope of this research is presented to limit the broad aspects of the complex socio-technical system studied in this research. In this same regard, limitations are identified in the institutional analysis conducted in this research. Moreover, the researcher does not possess a juridical background or experience that could provide a detailed insight into the GDPR regulations for example. Nevertheless, it is mentioned that this high level of detail is not the intention nor the scope of this research.

Concerning the stakeholder's analysis, more limitations can be found. This analysis was conducted via desk-studies and literature reviews that can have their faults as mentioned before. Moreover, to come up with this analysis no stakeholders where interviewed, and some assumptions regarding their roles and interactions were taken. In this regards the system description was not validated by the relevant stakeholders.

Requirements.

The requirements gathered in this research could also induce limitations, this is especially true in this case were the requirements were gathered through observation studies, desk research, and literature reviews. This entails that the value of these requirements is strongly dependent on the capabilities of the researchers to fully evaluate them. This is particularly true when it comes to novel research topics where there are not currently working BC-based MaaS system with the adoption of AVs in practice that could enable the researcher to study them to get a detailed real case for potential study. In addition to this, the used trip case scenario for gathering requirements is also limited to a specific case with a limited number of identified elements that could go wrong in that scenario. This is mainly done due to time and scope limitations of this research.

Other limitations are regarding the ability of the BC technologies to fully comply with privacy and specifically GDPR regulations hence some tradeoffs are needed. Furthermore, as is discussed in this research, in BC technologies it is not possible to delete data or documents that were previously stored in a blockchain.

Nevertheless, the decision of not to include personal information in the BC network could potentially mitigate this issue.

Other limitations regarding requirements like scalability and security are also identified in this research. The time limitations and the expertise of the researcher are not enabling to fully test these requirements. In addition to this, a tradeoff was made by focusing on more satisfying the requirements that relate to the key services that a MaaS will need which are represented in the BPMN models. In addition to this, a high level of details of these requirements are not needed in a proof of concept system proposed that have the intention to analyze an initial exploration of how a BC-based MaaS system with the adoption of AVs looks like.

System design and develop

Regarding the system design and develop additional limitations can be found. This is particularly true when it comes to the settings and technology advancements needed to design the proposed system. Moreover, this research is focused on a futuristic scenario which entails a high level of uncertainties regarding the development of the technologies needed for the feasibility of a system like the one proposed in this research.

The system design and architecture are based on the Ontology of Blockchain technologies developed by Tasca et al., (2017). This could create a tunnel vision of the design alternatives and decisions assessed to develop the BC architecture of this research. By doing so, other elements or solutions of the BC architecture and its component could not be considered if they weren't identified by the work of Tasca.

System demonstration

There are limitations to the ability to fully demonstrate the proposed system in this research. In this sense, it is not possible to fully demonstrate the artefacts in a real case nor the implementation of it. This is mainly because the technologies needed for its implementation are not fully developed. Moreover, level 5 of autonomy for the vehicles is not ready in addition to the implementation of the 5G network technology that is needed for the implementation of a fully autonomous vehicular ecosystem. In addition to this, the designed system remains at an abstract level which means that is it not possible to go into all the details of the system in this research.

System Evaluation

There is also some limitation in the evaluation of the system. The number of interviews and the type of interviews could also affect the evaluation of the system. In addition to this, the same researcher is involved in the design of the system as well as the evaluation which can lead to bias in the research. Being an ex-ante type of evaluation used for this research that could turn into false positives could mainly because a preliminary version of the artefacts is evaluated.

Environment

Another limitation that was beyond the investigator's control was the need to develop this thesis research during a global pandemic. Due to a novel virus (COVID19), multiple restrictions were imposed regarding social gatherings and social distance. This created some delays in the planning of this research and forced the interviews to only be via online telecommunications. The interviews could be affected by not having the ideal communication conditions of a personal interview.

8.4.2. Future Research

With the discussed limitations of this research, potential future research topics are proposed with the intention to address some of those limitations.

Is it possible to implement a prototype BC-based MaaS system with current technologies?
In this research is not considered the option to implement a BC-based MaaS system with the adoption of AVs mainly because the AVs technology is not ready. Nevertheless, it could be interesting for future research to implement a similar system with current AVs technology with the objective to see how the user interacts with such a system. In addition to this, a real-life test could be useful to gain insight into the implementation process of a system like the one proposed in this research. By doing so, it could be helpful to identify requirements of the system and design criteria in a more detailed manner that could help to future implementation.

To what extent the BC architecture presented in this research could be applied to other systems?
This research only focuses on the MaaS system that uses AVs. In this sense, it could be interesting to explore if the proposed BC architecture could be applied to a MaaS system that does not use AVs. For instance, it could be applied to multi-modal means of transportation that use public and private transportation means.

Is a blockchain-based MaaS system capable of handling sufficient scalability?
In the same way from the previous future research topic, applying a BC-based MaaS system to bigger environments like public transport scalability could be an issue. In this regard, it could be interesting to research if a BC-based MaaS system could be sufficient enough to handle a higher transaction throughput when is designed for a large-scale real-world implementation environment. In addition to this, a stress test could be designed to assess if the BC architecture is capable of handling a higher transaction throughput in a bigger environment.

Ho to design a BC architecture that fully complies with GDPR requirements?
As mentioned before BC technologies have some private issues and currently do not fully comply with GDPR requirements. In this sense, it could be interesting to research this topic with the help of a juridical expert. By doing so, it could be possible to create modifications to the BC architecture presented in this research to be able to fulfill the GDPR requirement at a greater detailed level.

8.5. Link with CoSEM programme

This research is part of the graduation requirements of the Complex Systems and Engineering (CoSEM) Master's programme. This programme focusses on designing complex socio-technical systems that are formed by multi-actor environments and technical complexities. This research is focused on designing a complex socio-technical system in the form of a BC architecture, business process, and reference architecture of a BC-based MaaS system with the adoption of AVs. In this research is possible to see the integration of technological components like MaaS, BC, and AV and their creative integration with both private and public organizations. Moreover, BC and AVs are novel technologies, and their interaction with MaaS results in a complex environment that lacks of a considerable knowledge base. This is done utilizing a Design Science Research (DSR) approach as a systematic approach to the engineering of the BC architecture, business processes, and references architecture as well as the design and evaluation for the proposed system. Furthermore, this research use BPMN and ArchiMate modeling tools that were learned in different courses during the duration of the CoSEM programme. The integration of these complex technologies in a mobility environment that interacts with users and multiple environments could be an ideal case for a CoSEM master thesis research.

Appendices

Appendix A

Literature Review A

In this review, journal and conference articles were searched by using specific keywords in reference databases like Scopus and Web of Science. For this review, white papers were discarded. Moreover, the specific keywords for selecting the articles were "mobility as a service" AND "autonomous vehicles". In addition to this, these keywords were used separately to gain insight into each of these different technologies. The selection process for these articles is achieved by reading the abstract and conclusions of these articles and separating articles from general autonomous technologies to the more specific target of this work.

The search criteria for this literature review was to only consider journal and conference articles written in English and discarding white paper or other types of literature. Moreover, a further selection process was achieved by only selecting applications on autonomous passenger vehicles. Other autonomous forms of transportation like planes, ships, drones, and trucks where discarded in order to have a unified type of vehicle to be analyzed. The topics and founding of this literature review are presented in *Table 10*, they are sorted by Author/Date in alphabetical order.

Table 13: A literature review of MaaS and AVs.

Author / Date	Source	Study Type	Topic/Founding's
(Athanasopoulou et al., 2019)	Journal Article	Q-methodology	There is a need to change business models in the automotive industry due to AVs. Personalized services, generic mobility services, shared mobility, and connected cars.
(Bothos et al., 2019)	Conference Article	Conceptual Model	New decentralized solutions are required in high complex MaaS ecosystems. Trusted and secure environments are needed in business processes and the handling of data. Self-sovereign identity could be a solution to privacy issues.
(Cai et al., 2019)	Journal Article	Discrete choice model	Acceptance of AVs as first and last-mile connections. Users consider privacy in AVs a relevant element.
(Cavazza et al., 2019)	Journal Article	Review Qualitative Descriptive	In the future, AVs will form part of our society. Great uncertainties in their implementation. Carsharing could be a substitute for cars, taxis, and buses.
(Cottrill, 2020)	Journal Article	Case Study	Consumer trust is a critical factor in MaaS ecosystems. Implications of GDPR in MaaS. Privacy issues should be raised early in a MaaS ecosystem. The importance of ensuring security on MaaS.
(Ferdman, 2019)	Journal Article	Review	Ownership of AVs and the impact on mobility. Implications on travel time, traffic, social justice, and well-being. Needs to define institutional settings.

(Fritschy & Spinler, 2019)	Journal Article	Qualitative Study	AVs will transform the automotive industry. The software will become more relevant in the industry. The value network will change its dependency.
(Karinsalo & Halunen, 2018)	Conference Article	Qualitative Model	In MaaS systems booking, ticketing, payment, and traveling must be in a trusted way. Lack of trust in the MaaS ecosystem. Trust, security, and safety need to be managed in a digital environment. AI and BC can serve as technology enablers in MaaS systems.
(Martin, 2019)	Journal Article	Review	AVs can make advancements in environmental sustainability and social fairness. Eco-social benefits will depend on sustainability science and political mobilization.
(Mehedi Hasan et al., 2018)	Journal Article	Chained of Things Framework Case Study	AVs will need to gain trust from users. Blockchain technology as a way to increase trust communication. The need for secure, private, and trustworthy AVs ecosystem.
(Mitra et al., 2019)	Conference Article	Review	AVs depend on a synergic data ecosystem. Data generation, acquisition, and processing of AVs. AVs environment must be secure, private, and trusted.
(Nobe, 2019)	Conference Article	Review	AVs as a mobility service. Mobility services will change the automotive industry. The emergency of mobility as a service.
(Pétervári & Pázmándi, 2018)	Journal Article	Review	A legal paradigm of AVs. Paradigm shifting in legal thinking.
(Romanski & Daim, 2019)	Journal Article	Review	Technology roadmap for AVs. The transport industry can increase profitability from automatization. Need for autonomic and organic computing processes with integration to other systems. Trust and privacy as market drivers.
(Seiberth & Gruendinger, 2018)	Journal Article	Study	The automotive industry can generate up to 50% of their income from data-driven services. Cultural transformation in the industry will be needed. BC can increase trust.
(Shabanpour et al., 2018)	Journal Article	Quantitative	Benefits for society and changes in network performance and travel behavior. Market penetration of AVs in Chicago could be more than 70%. Uncertainties on AVs security and privacy.
(Von Peinen et al., 2018)	Journal Article	System Dynamics Model Quantitative Study	AVs could increase offerings in ride-hailing services. High uncertainties with modeling processes.

Appendix B

Literature Review B

In this literature review, studies were searched by using specific keywords in reference databases like Scopus and Web of Science discarding white papers. The specific keywords for selecting the articles are mentioned in *Table 11* with their corresponding numbers of findings. The selection process for these articles is achieved by reading the abstract and conclusions of these articles. In this regard, only English articles were considered. Furthermore, the same way as the previous literature review only articles with research on autonomous passenger vehicles were used. This literature review was done with the intention to find out how BC can solve the main issues of security, privacy, and trust-related to AVs and MaaS systems. The main findings in these topics are presented in *Table 12*.

Table 14: Appendix B keywords and number of articles.

Keywords	Number of articles
(blockchain AND "autonomous vehicles")	86
(blockchain AND mobility)	150
(blockchain AND "mobility as a Service")	6
(blockchain AND "mobility as a service" AND "autonomous vehicles")	0
(blockchain AND "intelligent transportation system")	62
(blockchain AND "intelligent transportation system" AND "autonomous vehicles")	6

Table 15: A literature review of BC on AVs and mobility.

Author / Date	Main topic	Security	Privacy	Trust
(Buzachis et al., 2019)	BC in AVs networks and intersection management.	BC can be used to build security in the network.	BC can be used to build privacy in the network.	BC can be used to build trust in the network.
(Calvo & Mathar, 2018)	BC in AVs and ITS.	The main focus, define types and how to prevent attacks.	Anonymity, as part of the main problem, proposes a solution.	With BC there is no need for trusted third party authorities.
(H. Guo et al., 2019)	BC in AVs.	Mention possible vulnerabilities on the proposed solution	Not mentioned.	BC can increase trust in AVs accidents.
(Kandah et al., 2019)	BC in AVs and Smart Cities.	Critical and urgent need for design, propose solutions.	Privacy in communication must be ensured to increase the accuracy of the system.	Create and maintain trust is critical in the network.
(Kim, 2018)	BC in AVs and ITS.	Deeply explained and defined potential issues.	Deeply explained and defined the remaining issue.	Propose a BC-based trust network for intelligent vehicles.
(Mehedi Hasan et al., 2018)	BC in AVs and ridesharing.	States importance and constraints.	Relies only on BC capabilities for privacy.	Trusted party as a single point of failure. Provide a trusted BC environment.
(Mitra et al., 2019)	BC and AVs.	Different types of attacks, proposed framework.	A general overview of multiple issues.	A trusted environment is required for core functions and logic of AVs.
(Ortega et al., 2018)	BC in AVs networks.	Propose a security model oriented to messages.	Critical for V2X but not further developed.	One of the main requirements of a large network with heterogeneous devices.
(Pustišek et al., 2018)	BC in vehicles energy and mobility.	Relies on BC cryptographic capabilities.	Acknowledge BC no necessary to provide privacy.	BC as a trusted communication and computation platform.
(Saranti et al., 2019)	BC in AVs and mobility.	Hacker issue relies on policymakers.	The primary issue relies on policymakers.	BC has the potential to establish a trusted mobility system.
(Sharma et al., 2017)	BC in AVs networks.	Design principle, fundamental for client trust.	Design principle, fundamental for client trust.	BC can enable transportation systems that lack trust.
(Sharma et al., 2018)	BC in AVs and Smart City mobility.	Essential requirement and challenge, propose framework.	It is mentioned as related work.	Control of trust issues could be solved with BC.

(Yang et al., 2019)	BC in ITS.	Main goal requirement, propose framework.	Main goal requirement, propose framework.	Better counter measurements for trust verification are needed.

Appendix C

Expert evaluation

In this section, the summary of the expert's evaluations is writing by analyzing the audio files recorded during the interview process and summarizing the most important ideas discussed. The interview of Sélinde van Engelenburg is presented in Table 13. Additionally, the interview summary of Marijn Janssen is in Table 14. Finally, the interview of Patrick Fahim is presented in Table 15. In addition to this, the consent form from each interview is also presented in this section.

Table 16: Interview of Sélinde van Engelenburg.

#	Question
1	Could you state if the **research methodology** is valid for the intention and objective of this research?
R	SE: I was missing some details which make it difficult for me to determine the validity of the research methodology. Research about the evaluation, who are you going to interview, the expertise of the interviewers, how are you going to analyze the transcripts, I miss those details to see the logic behind it. In addition to this, the research sub-questions and research problems also are missing from the interview form. *GV: I left out those details because I think it was too much text to read.* SE: I miss those details to see the logic behind it. I really like that you applied the design science research, I think it is a rigorous method, so that is a good thing concerning the quality of the research. What I was wondering a little bit is the relevance, it seems that you did a lot of desk research and then you created a system model and then have semi-structured interviews and I was wondering if you also will interview people that will use the system or businesses that would provide their services by the system or something like that because I was missing a little bit for the relevance. *GV: No, I didn't do that, I only gather information from the literature reviews.* SE: It is not a big problem because every research misses something, but it will be good to mention it in the limitations.
2	Could you state if the defined **design requirements** are operationally defined?
R	SE: I think if you are talking about operational in the sense that you will be able to translate it into functionality that should be implemented on a low level, I think most of them are quite operational. I was wondering, especially in table 6 they are quite operational so that is good, I was wondering some of the GDPR elements because they seem more high level than the rest of it. I think you were missing some things. *GV: No, this is in the full thesis document only.* SE: For example, the gold binding of information, that you can only store data for a certain set time. One of the requirements of the GDPR is not only the user should be able to delete his/her

	information but the data cannot be store indefinitely, so there needs to be some time where the data is destroyed. Need to be some end-time where the data is deleted where the user requests it or not. It could be good to get help from a GDPR expert because. I studied GDPR in combination with blockchain before and had many discussions about it.
3	In your opinion: does the **design assumptions** make sense in the context of this research?
R	SE: I'm not sure, because when you use proof of work, for example, because the latency is kept low on purpose. But if you use pBFT and still have a BC structure you still need to collect all the transactions and put them into blocks after each other. This is still slower than a system where you would have to do that. However, I do not have the numbers in mind to say how big the problem is. What I usually do I compare it with Visa, they have a really high transaction they can process per second. If you want to use a BC on a large scale you will need a similar transaction throughput.
4	In your opinion: are the **design requirements** reflected on the **BC architecture** design decisions?
R	SE: Sometimes it is not clear to me how a design decision contributes to meeting certain requirements, especially the user requirements. This is, for example, the case for the consensus mechanism and requirements U5, U9, U10, and U11. SE: I did not see design decisions that were in conflict with the requirements, except for U7 about GDPR. As I am not a juridical expert, I cannot confirm that the design decisions make the system GDPR compliant.
5	In your opinion: is the **BC architecture** aligned with the **design decisions**?
R	SE: I don't see it reflected in the prototypes of figures 6 and 7 but they are in figure 5. Maybe it could be good to change this question or change the prototypes. For the data provider, how do you ensure that you can trust the data provider with the data and they are GDPR compliance? Maybe it would be good to add something about the trust in the data provider.
6	In your opinion: are the **design objectives**, **criteria,** and **assumptions** reflected in the **designed artefacts**?
R	SE: To me it seems that is reflected for the most part with the exemption of the trust of the data provider.
7	To what extent do you think that the **objectives** of this research are achieved?
R	SE: Yes, I think you did explore what it could look like, definitely. Because you have provided a design for this.
8	Do you see any other **objectives** that could be achieved by this research?
R	SE: As any BC research currently, one question is do we really need BC here? And I think it could be interesting to go into that question a little bit further, leaving open to the possible answer of yes and no. Another issue is that the design is made buy never tested in real-life, now in this case it might be difficult because we are looking to something in the future. But maybe it would be possible to implement some kind of prototype and let users interact with that. Not something to do on your research but something that could be discussed for future research because it is a lot of not and not possible for a Master thesis. But it would be important as well.

Table 17: Interview of Marijn Janssen.

#	Question
1	Could you state if the **research methodology** is valid for the intention and objective of this research?
R	Yes, I think so. But there are some limitations with the available literature, the number of interviews, the type of interviews. Research bias is also one of the issues because you are involved in designing and evaluating.
2	Could you state if the defined **design requirements** are operationally defined?
R	For example, data process gathering must be compliant with GDPR. I think that is a bit high level, for example, GDPR state data minimalization so how is data minimalized would be one of the questions. I understand that those are high-level requirements but GDPR consists of many components it is also about destroying data, not using data, how data is store in a secure way, encryption of data, etc. I think that should be detailed but it makes it quite difficult and some tradeoffs are needed. For example, if you decide to not store some data due to GDPR that will have limitations and disadvantages that you cannot trace back to the user so please say so because that is a limitation because you cannot conduct analysis in that data because you simply don't have the information.
3	In your opinion: do the **design assumptions** make sense in the context of this research?
R	I am not so worried about design assumptions; I am much more worried about what we discussed before about the requirements and trades off.
4	In your opinion: are the **design requirements** reflected on the **BC architecture** design decisions?
R	I am not able to judge that, to be honest. For example, one of the requirements is scalability and I don't see how scalability is achieved, if it is too much information, I cannot scale that. It is quite hard to do that, maybe a recommendation could be to do a stress test. Maybe you could also say that you cannot test all requirements and focus on the main requirement because this is a proof of concept. Same as the security requirements I am not able to judge that but I think that is not important because you are not a security expert. It is more important if you are able to cancel a trip for instance, or you have the geographical map or be able to make payments
5	In your opinion: is the **BC architecture** aligned with the **design decisions**?
R	Different levels of abstraction in the requirements same as you cannot test all the requirements but for me, that is not needed because your goal is a proof of concept. To have a good set of requirements that can be used as a base for the real development. But I think you have the right level of abstraction. I don't know if you have all the requirements but that is not needed in a high-level overview.
6	In your opinion: are the **design objectives**, **criteria,** and **assumptions** reflected in the **designed artefacts**?
R	Yes, I think they are. The designed artefact looks fine. I am not able the judge if it would make the users happy because I'm not the user but I think the diagrams look fine to me. And you can see some of the requirements in the diagrams so that is quite nice.
7	To what extent do you think that the **objectives** of this research are achieved?
R	I think so, I like the models, and is possible to get a feeling of how it looks like. The problem is you can't go into all the details and is an architecture to remains at an abstract level. Maybe you can make that explicit that remains at an abstract level. It gives a little bit about the components and the interaction between the components.
8	Do you see any other **objectives** that could be achieved by this research?

	I think what you did is a nice overview of how it looks like. I think you demonstrated that it is feasible and that is very important. But I think you don't look at requirements like scalability, security, etc. They are not included in the architecture but I think that is logical because you are not a scalability expert

Table 18: Interview of Patrick Fahim

#	Question
1	Could you state if the **research methodology** is valid for the intention and objective of this research?
R	PF: The objectives are very broad and actually one of my papers is to design a reference architecture model without the use of blockchain but I also used design research science so I guess it should be the right approach.
2	Could you state if the defined **design requirements** are operationally defined?
R	PF: So, you make it from a function if it is doable. For instance, why do you want the user to select the number of passengers? GV: Mainly for the system to determine the adequate type of vehicle for the number of passengers. PF: So, the context of this research is a platform like Uber but utilizing autonomous vehicles. The requirements for the autonomous vehicles make sense to me. So, I think the requirements are ok, most of them are already operational.
3	In your opinion: do the **design assumptions** make sense in the context of this research?
R	PF: Yes, is think in this case it makes sense to consider level 5 of autonomous vehicles and also the need for 5G networks with the advantage of lower latency for communications between the vehicles.
4	In your opinion: are the **design requirements** reflected on the **BC architecture** design decisions?
R	PF: Yes, I think some of the design requirements are reflected in the BC architecture.
5	In your opinion: is the **BC architecture** aligned with the **design decisions**?
R	PF: Yes, I think the BC architecture is aligned with the design decisions.
6	In your opinion: are the **design objectives**, **criteria,** and **assumptions** reflected in the **designed artefacts**?
R	PF: How do you come up with this reference model, did you look into the literature? GV: There are not many blockchains reference architectural models but I did find some reference architectures that use blockchain in logistics environments so I use those articles as reference for creating the model. PF: I really don't know much about architecture but if you base the architecture on your previous work, I thin the objectives, criteria, and assumptions are reflected.
7	To what extent do you think that the **objectives** of this research are achieved?
R	PF: Yes, I think is possible to see how a system like this would look like. The only problem is that this is a conceptual design and since you cannot implement this design it is hard to evaluate it. In this regard is also my question, to what extent can you use design science research because you cannot demonstrate much of it. This is a limitation of your research.
8	Do you see any other **objectives** that could be achieved by this research?

R PF: Yes, implementation could be the next step so you can evaluate not by just my opinion but you can actually evaluate it in practice, that is a logical next step, I think. You could also explore to what extent the architectures that you are making also could apply to other systems or field. That could be a nice extension of your research.

References

Accenture. (2018). *Autonomous Vehicles: The Race is On*. https://www.accenture.com/_acnmedia/pdf-73/accenture-autonomous-vehicles-the-race-is-on.pdf

Aste, T., Tasca, P., & Di Matteo, T. (2017). Blockchain Technologies: The Foreseeable Impact on Society and Industry. *Computer*, *50*(9), 18–28. https://doi.org/10.1109/MC.2017.3571064

Athanasopoulou, A., de Reuver, M., Nikou, S., & Bouwman, H. (2019). What technology enabled services impact business models in the automotive industry? An exploratory study. *Futures*, *109*(July 2018), 73–83. https://doi.org/10.1016/j.futures.2019.04.001

Berylls Strategy Advisors. (2018). *THE AUTONOMOUS FUTURE Berylls Report "Autonomous Mobility in the US Automotive Landscape 2030" BERYLLS.COM*.

Bothos, E., Magoutas, B., Mentzas, G., & Arnaoutaki, K. (2019). Leveraging blockchain for open mobility-as-a-service ecosystems. *Proceedings - 2019 IEEE/WIC/ACM International Conference on Web Intelligence Workshops, WI 2019 Companion*, 292–296. https://doi.org/10.1145/3358695.3361844

Bots, P. W. G., & Els Van Daalen, C. (2012). Designing socio-technical systems: Structures and processes. In *CESUN 2012: 3rd International Engineering Systems Symposium, Delft University of Technology, The Netherlands, 18-20 June 2012*.

Buzachis, A., Celesti, A., Galletta, A., Galletta, A., Fazio, M., & Villari, M. (2019). A secure and dependable multi-Agent autonomous intersection management (MA-AIM) system leveraging blockchain facilities. *Proceedings - 11th IEEE/ACM International Conference on Utility and Cloud Computing Companion, UCC Companion 2018*, 189–194. https://doi.org/10.1109/UCC-Companion.2018.00060

Cai, Y., Wang, H., Ong, G. P., Meng, Q., & Lee, D. H. (2019). Investigating user perception on autonomous vehicle (AV) based mobility-on-demand (MOD) services in Singapore using the logit kernel approach. *Transportation*, *46*(6), 2063–2080. https://doi.org/10.1007/s11116-019-10032-8

Calvo, J. A. L., & Mathar, R. (2018). Secure Blockchain-Based Communication Scheme for Connected Vehicles. *2018 European Conference on Networks and Communications, EuCNC 2018*, 347–351. https://doi.org/10.1109/EuCNC.2018.8442848

Casino, F., Dasaklis, T. K., & Patsakis, C. (2019). A systematic literature review of blockchain-based applications: Current status, classification and open issues. In *Telematics and Informatics* (Vol. 36, pp. 55–81). Pergamon. https://doi.org/10.1016/j.tele.2018.11.006

Castro, M., & Liskov, B. (1999). Practical Byzantine Fault Tolerance. *Proceedings of the Third Symposium on Operating Systems Design OSDI '99*, *February*, 1–172. http://pmg.csail.mit.edu/papers/osdi99.pdf

Castro, M., & Liskov, B. (2002). Practical Byzantine Fault Tolerance and Proactive Recovery. *ACM Transactions on Computer Systems*, *20*(4), 398–461. https://doi.org/10.1145/571637.571640

Cavazza, B. H., Gandia, R. M., Antonialli, F., Zambalde, A. L., Nicolaï, I., Sugano, J. Y., & De Miranda Neto, A. (2019). Management and business of autonomous vehicles: A systematic integrative bibliographic review. *International Journal of Automotive Technology and Management*, *19*(1–2), 31–54. https://doi.org/10.1504/IJATM.2019.098509

Christidis, K., & Devetsikiotis, M. (2016). Blockchains and Smart Contracts for the Internet of Things. In *IEEE Access* (Vol. 4, pp. 2292–2303). Institute of Electrical and Electronics Engineers Inc. https://doi.org/10.1109/ACCESS.2016.2566339

Clack, C. D., Bakshi, V. A., & Braine, L. (2016). *Smart Contract Templates: essential requirements and design options*. http://arxiv.org/abs/1612.04496

Cottrill, C. D. (2020). MaaS surveillance: Privacy considerations in mobility as a service. *Transportation Research Part A: Policy and Practice*, *131*, 50–57. https://doi.org/10.1016/j.tra.2019.09.026

David Leggett. (2019). European car market outlook is weak, despite October's jump, says GlobalData - GlobalData. *GlobalData*. https://www.globaldata.com/european-car-market-outlook-is-weak-despite-octobers-jump-says-globaldata/

de Bruijn, H., & Herder, P. M. (2009). System and actor perspectives on sociotechnical systems. *IEEE Transactions on Systems, Man, and Cybernetics Part A:Systems and Humans*, *39*(5), 981–992. https://doi.org/10.1109/TSMCA.2009.2025452

De Filippi, P. (2016). The interplay between decentralization and privacy: the case of blockchain technologies. *Journal of Peer Production*, *7*. https://ssrn.com/abstract=2852689

Denning, P. J. (1997). A New Social Contract for Research. *Communications of the ACM*, *40*(2), 132–134. https://doi.org/10.1145/253671.253755

Doucet, J. G. G., Scott, B., & Pallab, S. (2009). *Coherency Management: Architecting the Enterprise for Alignment, Agility and Assurance*. AuthorHouse. https://www.hugendubel.de/de/buch/john_goetze_gary_doucet_pallab_saha_scott_bernard-coherency_management-8758555-produkt-details.html?internal-rewrite=true%0Ahttp://books.google.com/books?hl=nl&lr=&id=_bXQjcc9lWgC&pgis=1

European Commission. (2016). *Cooperative, connected and automated mobility (C-ITS) - Mobility and Transport*. https://ec.europa.eu/transport/themes/its/c-its_en
European Parliament. (2018). *Report on autonomous driving in European transport*. https://www.europarl.europa.eu/doceo/document/A-8-2018-0425_EN.html
Ferdman, A. (2019). Corporate ownership of automated vehicles: discussing potential negative externalities. *Transport Reviews*, *0*(0), 1–19. https://doi.org/10.1080/01441647.2019.1687606
Freund, P. E. S., & Martin, G. T. (1993). *The ecology of the automobile*. Black Rose Books.
Fritschy, C., & Spinler, S. (2019). The impact of autonomous trucks on business models in the automotive and logistics industry–a Delphi-based scenario study. *Technological Forecasting and Social Change*, *148*. https://doi.org/10.1016/j.techfore.2019.119736
Government of the Netherlands. (2016). *Self-driving vehicles | Mobility, public transport and road safety*. https://www.government.nl/topics/mobility-public-transport-and-road-safety/self-driving-vehicles
Guo, H., Meamari, E., & Shen, C. C. (2019). Blockchain-inspired Event Recording System for Autonomous Vehicles. *Proceedings of 2018 1st IEEE International Conference on Hot Information-Centric Networking, HotICN 2018*, 218–222. https://doi.org/10.1109/HOTICN.2018.8606016
Guo, M., Liu, Y., Yu, H., Hu, B., & Sang, Z. (2016). An overview of smart city in China. In *China Communications* (Vol. 13, Issue 5, pp. 203–211). Editorial Department of China Communications. https://doi.org/10.1109/CC.2016.7489987
Hevner, A. R., March, S. T., Park, J., & Ram, S. (2004). Design science in information systems research. *MIS Quarterly: Management Information Systems*, *28*(1), 75–105. https://doi.org/10.2307/25148625
Higgins, T. (2017). How auto giants are dealing with a major threat - MarketWatch. *MarketWatch*. https://www.marketwatch.com/story/how-auto-giants-are-dealing-with-a-major-threat-2017-07-05
Husak, A., Politis, M., Shah, V., Eshuis, R., & Grefen, P. (2015). *Reference architecture for mobility-related services : a reference architecture based on GET service and SIMPLI-CITY project architectures*. *477*(July). www.tue.nl/taverne
ING. (2018). *Car sharing unlocked*. https://think.ing.com/uploads/reports/ING_-_Car_sharing_unlocked.pdf
Jim, E. (2019). Carpocalypse now: Lyft's founders are right - we're in the endgame for cars. *Business Insider*. https://www.businessinsider.nl/carpocalypse-cars-automobile-sales-data-us-europe-2019-3?international=true&r=US
Jittrapirom, P., Caiati, V., Feneri, A. M., Ebrahimigharehbaghi, S., Alonso-González, M. J., & Narayan, J. (2017). Mobility as a service: A critical review of definitions, assessments of schemes, and key challenges. *Urban Planning*, *2*(2), 13–25. https://doi.org/10.17645/up.v2i2.931
Johannesson, P., & Perjons, E. (2014). An Introduction to Design Science. In *The Design Method*. Springer International Publishing. https://doi.org/10.1007/978-3-319-10632-8
Kamargianni, M., & Matyas, M. (2017). The Business Ecosystem of Mobility-as-a-Service. *96th Transportation Research Board (TRB) Annual Meeting, Washington DC, 8-12 January 2017*, *January*, 8–12. http://discovery.ucl.ac.uk/10037890/1/a2135d_445259f704474f0f8116ccb625bdf7f8.pdf
Kandah, F., Huber, B., Skjellum, A., & Altarawneh, A. (2019). A Blockchain-based Trust Management Approach for Connected Autonomous Vehicles in Smart Cities. *2019 IEEE 9th Annual Computing and Communication Workshop and Conference (CCWC)*, 0544–0549. https://doi.org/10.1109/CCWC.2019.8666505
Karinsalo, A., & Halunen, K. (2018). Smart Contracts for a Mobility-as-a-Service Ecosystem. *Proceedings - 2018 IEEE 18th International Conference on Software Quality, Reliability, and Security Companion, QRS-C 2018*, 135–138. https://doi.org/10.1109/QRS-C.2018.00036
Kim, S. (2018). Blockchain for a Trust Network Among Intelligent Vehicles. In *Advances in Computers* (Vol. 111, pp. 43–68). Elsevier. https://doi.org/10.1016/bs.adcom.2018.03.010
Li, Y., & Voege, T. (2017). Mobility as a Service (MaaS): Challenges of Implementation and Policy Required. *Journal of Transportation Technologies*, *07*(02), 95–106. https://doi.org/10.4236/jtts.2017.72007
Maier, M. W., Emery, D., & Hilliard, R. (2001). Software architecture: Introducing IEEE standard 1471. *Computer*, *34*(4), 107–109. https://doi.org/10.1109/2.917550
Manville, C., Europe, R., Millard, J., Technological Institute, D., Liebe, A., & Massink, R. (2014). *DIRECTORATE GENERAL FOR INTERNAL POLICIES POLICY DEPARTMENT A: ECONOMIC AND SCIENTIFIC POLICY Mapping Smart Cities in the EU STUDY*.
Markus, M. L., Majchrzak, A., & Gasser, L. (2008). A design theory for systems that support emergent knowledge processes. *Design Science Theories and Research Practices*.
Martin, G. (2019). An Ecosocial Frame for Autonomous Vehicles. *Capitalism, Nature, Socialism*, *30*(4), 55–70. https://doi.org/10.1080/10455752.2018.1510531
McDonald, N. C. (2015). Are millennials really the "go-Nowhere" Generation? *Journal of the American Planning Association*, *81*(2), 90–103. https://doi.org/10.1080/01944363.2015.1057196
Mehedi Hasan, M. G. M., Datta, A., Ashiqur Rahman, M., & Shahriar, H. (2018). Chained of Things: A Secure and Dependable Design of Autonomous Vehicle Services. *Proceedings - International Computer Software and Applications Conference*, *2*, 498–503. https://doi.org/10.1109/COMPSAC.2018.10283

Mishra, S., & Sil, S. (2019). *Blockchain Reference Architecture – A Smarter way to implement Agile and Effective Blockchain Solutions*. www.niit-tech.com

Mitra, S., Bose, S., Gupta, S. Sen, & Chattopadhyay, A. (2019). Secure and Tamper-resilient Distributed Ledger for Data Aggregation in Autonomous Vehicles. *2018 IEEE Asia Pacific Conference on Circuits and Systems, APCCAS 2018*, 548–551. https://doi.org/10.1109/APCCAS.2018.8605625

Monios, J., & Bergqvist, R. (2020). Logistics and the networked society: A conceptual framework for smart network business models using electric autonomous vehicles (EAVs). *Technological Forecasting and Social Change*, *151*. https://doi.org/10.1016/j.techfore.2019.119824

Mora, L., Deakin, M., & Reid, A. (2019). Combining co-citation clustering and text-based analysis to reveal the main development paths of smart cities. *Technological Forecasting and Social Change*, *142*, 56–69. https://doi.org/10.1016/j.techfore.2018.07.019

Nam, T., & Pardo, T. A. (2014). The changing face of a city government: A case study of Philly311. *Government Information Quarterly*, *31*(SUPPL.1), S1–S9. https://doi.org/10.1016/j.giq.2014.01.002

Nguyen, T. H., Partala, J., & Pirttikangas, S. (2019). Blockchain-based mobility-as-a-service. *Proceedings - International Conference on Computer Communications and Networks, ICCCN*, *2019-July*(section II), 1–6. https://doi.org/10.1109/ICCCN.2019.8847027

Nicola, S., & Berhmann, E. (2018). 'Peak Car' and the End of an Industry. *Bloomberg*. https://www.bloombergquint.com/business/-peak-car-and-the-end-of-an-industry

Nobe, T. (2019). Foreseeable Industrial Changes of Automotive and Transportation Driven by Semiconductors. *Proceedings of the International Symposium on Power Semiconductor Devices and ICs*, *2019-May*, 11–16. https://doi.org/10.1109/ISPSD.2019.8757592

Object Management Group. (2011). Business Process Model and Notation (BPMN). In *The Complete Business Process Handbook* (Vol. 1). https://doi.org/10.1007/978-3-642-33155-8

Offermann, P., Blom, S., Schönherr, M., & Bub, U. (2010). Artifact Types in Information Systems Design Science-A Literature Review. In *LNCS* (Vol. 6105). Springer-Verlag.

Oliveira, L., Bauer, I., Zavolokina, L., Bauer, I., & Schwabe, G. (2018). To Token or not to Token : Tools for Understanding Blockchain Tokens. *International Conference on Information Systems 2018, ICIS 2018*, *October*, 1–17. https://doi.org/10.5167/UZH-157908

Ortega, V., Bouchmal, F., & Monserrat, J. F. (2018). Trusted 5G Vehicular Networks: Blockchains and Content-Centric Networking. *IEEE Vehicular Technology Magazine*, *13*(2), 121–127. https://doi.org/10.1109/MVT.2018.2813422

Pétervári, K., & Pázmándi, K. (2018). Law and Economic Analysis of the Legal Environment Related to the Autonomous Vehicles - Is There a Legal Paradigm Shift? *IOP Conference Series: Materials Science and Engineering*, *448*(1). https://doi.org/10.1088/1757-899X/448/1/012030

Pietsch, B. (2020). Nissan is launching a $700-a-month subscription service that lets you switch to a different car every day. Here's how it works. *Business Insider*. https://www.businessinsider.nl/nissan-switch-car-subscription-service-swap-vehicles-daily-2020-2/

Pustišek, M., Kos, A., & Sedlar, U. (2018). Blockchain based autonomous selection of electric vehicle charging station. *Proceedings - 2016 International Conference on Identification, Information and Knowledge in the Internet of Things, IIKI 2016*, *2018-Janua*, 217–222. https://doi.org/10.1109/IIKI.2016.60

Rivera, R., Robledo, J. G., Larios, V. M., & Avalos, J. M. (2017). How digital identity on blockchain can contribute in a smart city environment. *2017 International Smart Cities Conference, ISC2 2017*, *00*(c), 17–20. https://doi.org/10.1109/ISC2.2017.8090839

Rocha, H., & Ducasse, S. (2018). *Preliminary Steps Towards Modeling Blockchain Oriented Software*. https://doi.org/10.1145/3194113.3194123

Romanski, B., & Daim, T. (2019). A Technology Roadmap to Uncontested Market Space Using Autonomous Vehicles in the Transportation Industry. *IEEE Engineering Management Review*, *47*(1), 67–76. https://doi.org/10.1109/EMR.2019.2900435

Rossi, M., Mueller-Bloch, C., Thatcher, J. B., & Beck, R. (2019). Blockchain Research in Information Systems: Current Trends and an Inclusive Future Research Agenda. *Journal of the Association for Information Systems*, *09*, 1390–1405. https://doi.org/10.17705/1jais.00571

Salonen, A., & Haavisto, N. (2019). Towards Autonomous Transportation. Passengers' Experiences, Perceptions and Feelings in a Driverless Shuttle Bus in Finland. *Sustainability*, *11*(3), 588. https://doi.org/10.3390/su11030588

Saranti, P. G., Chondrogianni, D., & Karatzas, S. (2019). Autonomous vehicles and blockchain technology are shaping the future of transportation. *Advances in Intelligent Systems and Computing*, *879*, 797–803. https://doi.org/10.1007/978-3-030-02305-8_96

Schindewolf, S. (2018). *How to model Blockchain using Archimate*. https://stefanschindewolf.de/2018/02/07/how-enterprise-architects-view-blockchain/

Seiberth, G. ;, & Gruendinger, W. (2018). Data-driven Business Models in Connected Cars. *Mobility Services and Beyond*, *18*(01), 57. https://www.bvdw.org/fileadmin/user_upload/20180509_bvdw_accenture_studie_datadrivenbusinessmodels.pdf

Shabanpour, R., Shamshiripour, A., & Mohammadian, A. (2018). Modeling adoption timing of autonomous vehicles: innovation diffusion approach. *Transportation*, *45*(6), 1607–1621. https://doi.org/10.1007/s11116-018-9947-7

Shaheen, S. A., & Cohen, A. P. (2012). Carsharing and Personal Vehicle Services: Worldwide Market Developments and Emerging Trends. *International Journal of Sustainable Transportation*, *7*(1), 5–34. https://doi.org/10.1080/15568318.2012.660103

Sharma, P. K., Kumar, N., & Park, J. H. (2018). Blockchain-based Distributed Framework for Automotive Industry in a Smart City. *IEEE Transactions on Industrial Informatics*, 1–1. https://doi.org/10.1109/TII.2018.2887101

Sharma, P. K., Moon, S. Y., & Park, J. H. (2017). Block-VN: A distributed blockchain based vehicular network architecture in smart city. *Journal of Information Processing Systems*, *13*(1), 184–195. https://doi.org/10.3745/JIPS.03.0065

Skeete, J. P. (2018). Level 5 autonomy: The new face of disruption in road transport. *Technological Forecasting and Social Change*, *134*, 22–34. https://doi.org/10.1016/j.techfore.2018.05.003

Sommerville, I. (2016). *Software Engineering: Global Edition, Tenth Edition*. https://doi.org/10.1136/bmj.1.5802.756-b

Spijkerboer, E. C. (2019). *Blockchain based transaction processing system : a reference architecture for an integrated blockchain based transaction processing system*.

Tasca, P., & Liu, S. (2016). The Evolution of the Bitcoin Economy: Extracting and Analyzing the Network of Payment Relationships. *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.2808762

Tasca, P., Thanabalasingham, T., & Tessone, C. J. (2017). *Ontology of Blockchain Technologies. Principles of Identification and Classification*.

Regulation (EU) 2016/679 of the European Parliament and of the Council of 27 April 2016 on the protection of natural persons with regard to the processing of personal data and on the free movement of such data, Official Journal of the European Union 1 (2016). https://doi.org/10.5771/9783845266190-974

The Open Group. (2018). Archimate 3.1 Specification. In *The Open Group*. https://pubs.opengroup.org/architecture/archimate3-doc/chap01.html#_Toc10045267

Tsukerman, M. (2016). The Block is hot: A Survey of the State of Bitcoin Regulation and Suggestions for the Future. *Berkeley Technology Law Journal*, *30*, 1127–1169. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2587421

Utriainen, R., & Pöllänen, M. (2018). Review on mobility as a service in scientific publications. *Research in Transportation Business and Management*, *27*, 15–23. https://doi.org/10.1016/j.rtbm.2018.10.005

Verschuren, P., & Hartog, R. (2005). Evaluation in design-oriented research. *Quality and Quantity*, *39*(6), 733–762. https://doi.org/10.1007/s11135-005-3150-6

Viswanathan, R., Dasgupta, D., & Govindaswamy, S. R. (2019). Blockchain solution reference architecture (BSRA). *IBM Journal of Research and Development*, *63*(2). https://doi.org/10.1147/JRD.2019.2913629

Von Peinen, A., Bohmer, A. I., & Lindemann, U. (2018). System Dynamics as a Tool for Data Driven Business Model Design in the Context of Autonomous Ride Hailing. *2018 IEEE International Conference on Engineering, Technology and Innovation, ICE/ITMC 2018 - Proceedings*, 0–5. https://doi.org/10.1109/ICE.2018.8436306

Westin, A. F. (1967). Privacy and Freedom annotated. In *Privacy and Freedom* (Vol. 22). American Bar Association. https://doi.org/10.2307/40708684

Wong, Y. Z., Hensher, D. A., & Mulley, C. (2020). Mobility as a service (MaaS): Charting a future context. *Transportation Research Part A: Policy and Practice*, *131*(October 2019), 5–19. https://doi.org/10.1016/j.tra.2019.09.030

Xu, X., Weber, I., Staples, M., Zhu, L., Bosch, J., Bass, L., Pautasso, C., & Rimba, P. (2017). A Taxonomy of Blockchain-Based Systems for Architecture Design. *Proceedings - 2017 IEEE International Conference on Software Architecture, ICSA 2017*, 243–252. https://doi.org/10.1109/ICSA.2017.33

Yang, Y.-T., Chou, L.-D., Tseng, C.-W., Tseng, F.-H., & Liu, C.-C. (2019). Blockchain-based Traffic Event Validation and Trust Verification for VANETs. *IEEE Access*, *7*, 1–1. https://doi.org/10.1109/access.2019.2903202

Yli-Huumo, J., Ko, D., Choi, S., Park, S., & Smolander, K. (2016). Where Is Current Research on Blockchain Technology?—A Systematic Review. *PLOS ONE*, *11*(10), e0163477. https://doi.org/10.1371/journal.pone.0163477

Yuan, Y., & Wang, F. Y. (2016). Towards blockchain-based intelligent transportation systems. *IEEE Conference on Intelligent Transportation Systems, Proceedings, ITSC*, 2663–2668. https://doi.org/10.1109/ITSC.2016.7795984

Zheng, C., Yuan, J., Zhu, L., Zhang, Y., & Shao, Q. (2020). From digital to sustainable: A scientometric review of smart city literature between 1990 and 2019. *Journal of Cleaner Production*, *258*, 120689. https://doi.org/10.1016/j.jclepro.2020.120689

Zheng, Z., Xie, S., Dai, H., Chen, X., & Wang, H. (2017). An Overview of Blockchain Technology: Architecture, Consensus, and Future Trends. *Proceedings - 2017 IEEE 6th International Congress on Big Data, BigData Congress 2017*, 557–564. https://doi.org/10.1109/BigDataCongress.2017.85