International Journal of Transport Development and Integration
Vol. 7, No. 3, September, 2023, pp. 153-165
Journal homepage: http://iieta.org/journals/ijtdi

Modeling Waymo's Shared Autonomous Vehicle Service in Phoenix Using *e³value*

João Nina Rosa[1*], António Reis Pereira[1], Flavia Santoro[2], Jaap Gordijn[3], Miguel Mira da Silva[4]

[1] Department of Engineering and Management, Instituto Superior Técnico, Universidade de Lisboa, Lisboa 1049-001, Portugal
[2] Instituto de Tecnologia e Liderança, São Paulo 05508-070, Brazil
[3] Department of Computer Science, Vrije Universiteit Amsterdam, Amsterdam 1081, The Netherlands
[4] Department of Information Systems, Instituto Superior Técnico, Universidade de Lisboa, Lisboa 1049-001, Portugal

Corresponding Author Email: joaopnrosa@tecnico.ulisboa.pt

https://doi.org/10.18280/ijtdi.070301

Received: 8 May 2023
Revised: 29 June 2023
Accepted: 10 July 2023
Available online: 27 September 2023

Keywords:
shared, autonomous, Waymo, e³value, Phoenix, modeling, economic benefits

ABSTRACT

The research objective of this work is to analyze what is behind the self-driving offer implemented in Phoenix (Arizona), by Waymo, a service called Waymo One, and model it in *e³value*. Through a comprehensive literature review and the application of *e³value* modeling, this study focuses on the fundamental principles and technological advancements of self-driving vehicles and shared mobility services. Waymo's operations and ecosystem are systematically modeled, providing a detailed representation of the service. Results demonstrate the potential improvements in road safety, traffic reduction, and emissions mitigation achieved through shared autonomous mobility. The *e³value* model offers a holistic perspective on the interactions and value exchanges among stakeholders, including passengers, vehicle operators, infrastructure providers, and regulatory bodies, elucidating their roles within the shared autonomous mobility ecosystem. The idea is to support the development of other shared autonomous vehicles trials around the world. Main goal is to improve the shared autonomous mobility offer, which means better safety on the road, reduced traffic, and lower emissions in the metropolitan areas of cities. Therefore, modeling Waymo One can be a basis for the extension of shared autonomous vehicles businesses to other companies in different geographies.

1. INTRODUCTION

A self-driving car is a vehicle that can operate autonomously with the help of sensors and software without the need for human intervention. Autonomous vehicles, driverless vehicles, and robotic vehicles are other terms for self-driving cars [1]. Self-driving cars are already on the road, but most countries have yet to license fully autonomous vehicles. Currently, cars are semi-automated and require human intervention. Autonomous cars work with the use of different technologies, including LiDAR, sensors, laser lights, GPS, computer vision and radar, among many others.

All of the sensors' input is processed by sophisticated software, which plots a path and sends instructions to the car's actuators, which control the throttle, brakes, and steering. The software follows traffic rules and navigates through the roads due to obstacle avoidance algorithms, predictive modeling, and object recognition.

We focus on the use of self-driving cars in the United States in this paper because we are modeling a Waymo project implemented in Phoenix. The technology for self-driving cars has received a lot of attention in this country, not to mention the business, policy, legal, ethical, and regulatory challenges. It is safe to say that almost every day, journalists and columnists cover the latest developments in this technology, owing largely to safety concerns about these vehicles. The business models of automotive manufacturers operating in the US are in the spotlight of the world, namely because of the great advances on part of Tesla. Autonomous vehicles have the potential to remake not only the automotive industry but as well transportation services and infrastructure requirements for cities [2].

The combined awareness of energy issues and extreme pollution within cities have also boosted the big push of autonomous vehicles technology innovation. Regulations have imposed restrictions on vehicles in cities and the relationship between the user and the vehicle has been changing and will continue to change. In city metropolitan areas the concept of ownership of the vehicle replaces its use. As the relationship to everyday objects turned into customary contracts with the mobile phone, and the laptop computer, the idea of becoming a single user of a means of transport is becoming a reality with the appearance of autonomous cars [3].

In the context of autonomous vehicles, extensive literature has highlighted their potential benefits in terms of mobility, traffic, emissions, and safety [4, 5].

As autonomous cars start gaining relevance, it is becoming important for companies to conduct trial runs along with services such as ride-hailing in different regions of the world. However, there are gaps in research regarding the business models and operational dynamics of shared autonomous vehicle services, particularly in the context of the ride-hailing industry. This study addresses these gaps by analyzing and modeling Waymo One, a shared autonomous vehicle ride-

hailing service in Phoenix, Arizona, using the *e³value* methodology. Filling these research gaps, this study contributes to the advancement of shared autonomous mobility and provides insights for future research.

The primary objective of this research is to analyze the business model behind Waymo One, a shared autonomous vehicle ride-hailing service implemented in Phoenix, Arizona by Waymo, and to model it using the *e³value* methodology. It is also our goal to understand the operational dynamics, stakeholder interactions, and value propositions within the shared autonomous mobility domain, with the goal of supporting the development and expansion of similar initiatives globally.

To support our work, we resort to using the *e³value* methodology to model this business that has been implemented in Phoenix by Waymo, called Waymo One. Understanding Waymo One business concepts in-depth is the first step in developing such ideas.

The *e³value* methodology, a recognized approach for designing e-Business models, plays a pivotal role in this study. By employing *e³value* modeling, we can comprehensively analyze the intricate dynamics and interdependencies within the shared autonomous mobility domain. This methodology facilitates a thorough and collaborative understanding of the underlying concepts and profit drivers involved in the business model of Waymo One, Waymo's shared autonomous vehicle ride-hailing service in Phoenix. Through the *e³value* approach, we gain valuable insights into the value propositions, stakeholder interactions, and revenue generation mechanisms that drive the success of such services. This detailed understanding of the *e³value* model allows us to advance our knowledge of autonomous vehicle implementation in the ride-hailing industry and provides a solid foundation for future developments and improvements in the broader autonomous mobility market segment.

The final goal is to reach an understanding of how autonomous vehicles are being implemented in ride-hailing businesses, through the Phoenix ecosystem, and how they can evolve incorporated in the future of the autonomous mobility market segment.

This document is structured as follows. In section 2 we define research background, in section 3 we describe what is the research methodology adopted in this paper. The modeling of what is behind shared autonomous vehicles in Phoenix using the *e³value* is presented in section 4, along with a comprehensive interpretation of those models. In section 5 we establish what we have learned throughout the study and writing of this paper. Finally in section 6 we set up the final conclusions.

2. RESEARCH BACKGROUND

According to the information collected at an early stage and to answer the central questions of the present study, it was pertinent to frame and conceptualize the main topics, namely Autonomous Vehicles, Waymo and *e³value* once these are central topics from which our work is based on. It was important to have a good background research supported with a solid literature review as a starting point to our work. In this way, the three topics presented are centered on relevant and current studies to better understand how they relate to each other and sustain the framework of this work.

2.1 *e³value*

The *e³value* methodology [6] is a conceptual modeling tool for analyzing the feasibility and sustainability of a business idea. The *e³value* methodology [7] provides means to explore value webs. Value webs consist of organizations or enterprises that offer a service to the market, it symbolizes the linked links that exist between different businesses inside a business ecosystem, where value is created, exchanged, and consumed. The concept of a value web highlights the collaborative aspect of value production and distribution among participating actors. The *e³value* methodology makes the exploration of a networked business idea easily comprehensible. The "*e³*" stands for "Economics of Electronic Environments", and the "Value" stands for the value exchanges in business environments.

The *e³value* was chosen as the modeling methodology for this study because it provides a comprehensive framework for analyzing the feasibility and profitability of a business idea within a networked context. It allows the study of value webs and the exchange of value objects through value interfaces, showing economic reciprocity in business transactions. The *e³value* methodology's modeling components gives a deeper understanding of online business models and support profitability assessment for all stakeholders involved. Its focus on value networks and economic value aligns well with the objectives of this study, which aims to analyze and model the business dynamics of shared autonomous vehicles. By utilizing *e³value*, this research can gain valuable insights into the value exchanges, stakeholders' roles, and profitability drivers within the shared autonomous mobility ecosystem.

The value objects, such as money, services, products, data, etc., are exchanged through value ports which are grouped into value interfaces. These value interfaces model the economic reciprocity that exists in every business transaction [8].

For example, a customer's need is satisfied if a customer can successfully order a service from a company. To satisfy this need, an exchange of value objects (service against money) via an interface is conducted. These activities are performed in exchange for value objects. For instance, in the case of a service provider, the value object, which is the service, is exchanged in return for money. The boundary element at the company indicates the end of value transfers.

The *e³value* ontology stipulates that the actors exchange value objects by means of value activities. The value activity should generate profit for the actor. Production, trade, distribution, and consumption of value objects are examples of these activities. Value actions are undertaken with the goal of generating profit for the actors involved and are critical to the value web's operation. Deeper insight in *e³value* modeling shows that this method only covers exchange and trade processes but leaves out production and conversion processes. The *e³value* model only focuses on operational level (what has happened) and not on management policies (what could or should happen). It also enables value network modeling, aiming to provide a common understanding of a business idea executed by a network of actors that jointly create, distribute, and consume value in inter-organizational business models. We can assume that it considers the economic value of a value proposition. The purpose for which the *e³value* was created is to reach a better understanding of an online business model by the stakeholders, and to be able to do profitability assessment for all parties involved [6]. It provides a group of modeling components that are used to build the models [7].

2.2 Autonomous vehicles

According to the American National Highway Traffic Safety Administration [9], autonomous vehicles are classified into 6 levels, from Level 0 to Level 5. Levels of driving automation are:

- 0 no automation,
- 1 driver assistance,
- 2 partial automations,
- 3 conditional automations,
- 4 high automations,
- 5 full automations.

Grouping according to the actions that the driver has to do, it can be:

- full manual controlled drive (0, 1),
- manual controlled automatic drive systems (2, 3),
- optional manual driving controlled car (4),
- no manual driving control (5).

At Level 0, no automation is present, and the driver has complete control of the vehicle. In Level 1, there are already driver assistance systems, offering features like lane monitoring and adaptive cruise control. Level 2 vehicles have partial automation capabilities, enabling it to handle specific tasks such as steering and acceleration under certain conditions, while the driver remains responsible for monitoring the surroundings [10].

Modern vehicles are labeled as level 3, where multiple safety systems are handled by the system (lane monitoring, adaptive cruise control, brake assistance, parking assistance), but the driver needs to be always alert to intervene and cannot leave his hands out of the steering wheel (although many modern cars can drive autonomously for a period of time, by law it is required that the driver keeps the hands in the steering wheel all the time). Level 4 vehicles handle multiple safety systems and operate in a wider range of environments.

Level 5 automation is the end goal of autonomous driving, where all the systems in the car are operated by the Advanced Driver Assistance Systems, under all driving conditions (such as snow-covered roads and unmarked dirt roads) and would not require any human intervention. In practice, the steering wheel is useless [10].

This, however, still requires significant advances in multiple areas, such as sensor technology, computing systems and automotive networks, as referred by. The Waymo car right now is considered to be between Level 4 and Level 5 [11].

In the last few years, we have seen a big development in the technology that supports this, such as sensors, cameras, LiDAR, Artificial Intelligence (along with Machine Learning and Deep Learning), Neuronal Networks, 5G, Big Data and the Cloud.

Many research articles have been published in the academic literature describing the technological advancement of Autonomous Vehicles [12]. However, academic literature outlining the autonomous vehicle can be very contradictory in terms of opinions (both positive and negative) in cities and how policies are being introduced to promote or address various disruptive effects is fairly limited [13]. Anyway, a recent prediction suggests that by 2045 autonomous vehicles would take up half of all the traffic on the roads in the world [4, 14].

2.3 Waymo

To understand the reason that Waymo is entering this new market of shared vehicles, we first need to understand the value propositions which the company is governed by. It is important to note that Waymo is a subsidiary of Alphabet Inc, the parent company of Google, and as such, shares the same values of these companies.

As advertised, Google has strong social and moral awareness in all its businesses ramifications, and this is a principle of the Alphabet Inc. group that is transversal to all its companies, where Waymo is no different. Waymo's spin-off is based on a set of fundamental value propositions that are critical in determining its business scope. To begin, the company strives to improve transportation for people all over the world by making it safe and simple to move people and things. Second, Waymo intends to build a more efficient network by leveraging new technologies such as self-driving cars, which will significantly reduce the cost of public transportation. Furthermore, Waymo intends to transition to a fully autonomous service that is less expensive than car ownership while improving urban quality of life. Another important goal is to reduce CO_2 emissions and maximize people's useful time when traveling, whether for work, tasks, rest, or other reasons. As stated by Margulis and Goulding [15], these goals are the foundation on which Waymo was founded, to improve people's lives and help promote planet sustainability.

Google started investing in the autonomous vehicle's technology in 2009, with the creation of Google car. With the growing importance of this technology the company decided to create Waymo in order to have an entire company fully dedicated to the research and development of the technology. At the same time Waymo was founded, Tesla was also starting to invest a lot of its resources in this area of expertise.

Nevertheless, since then, Waymo has led the pack of autonomous vehicle developers, setting the stage for what could be a massive transformation in personal mobility. The company was among the first to deploy fully driverless cars, and its sights were set on ride-hailing and freight-hauling as its commercial pursuits.

Waymo's mission to reduce traffic injuries and fatalities while also improving mobility for all has led to the company expanding the deployment of automated vehicles on public roads without a human driver behind the wheel. As part of this process, the company is committed to providing the public with relevant and informative data about the demonstrated safety of their driving system that is named Waymo Driver.

Waymo is not the only company transforming the market with autonomous vehicles and mobility-as-a-service. Several other companies and players have emerged, each with their own unique perspectives and contributions to the sector. Tesla, a major contender, has made significant efforts in self-driving technology, as evidenced by their advanced autopilot feature [16]. Automakers such as General Motors, Ford, and BMW are aggressively expanding their autonomous car projects, frequently forming alliances with ride-hailing firms to investigate creative mobility options [17]. Uber and Lyft have already entered the fray, incorporating self-driving cars into their ride-hailing platforms [18]. Meanwhile, rising firms like Cruise, Zoox, and Aurora are making significant gains toward deploying autonomous vehicles at scale [19].

It is important to realize that Waymo self-driving cars go through a more comprehensive set of tests than humans do, as proven by its safety report. Its approach to safety is the scope of the design and testing regime present in the company's assessment of the vehicle's safety. For such vehicles to work

at all, a raft of sensors is needed to always provide the vehicle's software with situation awareness. Unlike human drivers, the self-driving car can continuously sense its 360-degree surroundings using multiple sensors: color-aware visible light cameras, radar transceivers, three Lidar sensors (short, medium, and long-range), audio detectors, and GPS receivers. Moreover, a great deal of redundancy is built into the system to provide backup capacity in the event of various failure scenarios.

The Waymo vehicles have accumulated four million miles of driving on city streets of California, Washington state, Arizona and Texas. In addition, each day, as many as 25,000 virtual Waymo self-driving vehicles drive up to eight million miles in simulation for an accumulated total of 2.5 billion simulated miles during self-driving car development.

According to the safety report, Waymo has established a private 91-acre closed-course testing facility in California, specifically designed and built for their own unique testing needs. This private facility is set up like a mock city, with everything from high-speed roads to suburban driveways to a railroad crossing. The team uses this and other closed-course facilities to validate new software before it is released to the fleet of vehicles on the road, as well as to test rare scenarios so vehicles gain experience with unusual situations. The simulation capability is especially important because it allows Waymo to test any new software or hardware in parallel, which would take far too long to test in the real world.

Right now, Waymo is running a fully autonomous ride-hailing service, Waymo One, in the East Valley of Phoenix, Arizona, in Figure 1 is represented the area of operations. This service is already fully functional and operating with the population of Phoenix for anyone to use [20]. It is a simple service that uses an application like Uber and Lyft to request a taxi service from any point A to any B, within the designated area, but without the presence of a human at the wheel. This service is now expanding its operations to San Francisco, California, using a new fleet of fully electric cars, the Jaguar I-Pace, instead of the Chrysler Pacifica Minivan (hybrid car) used in Arizona.

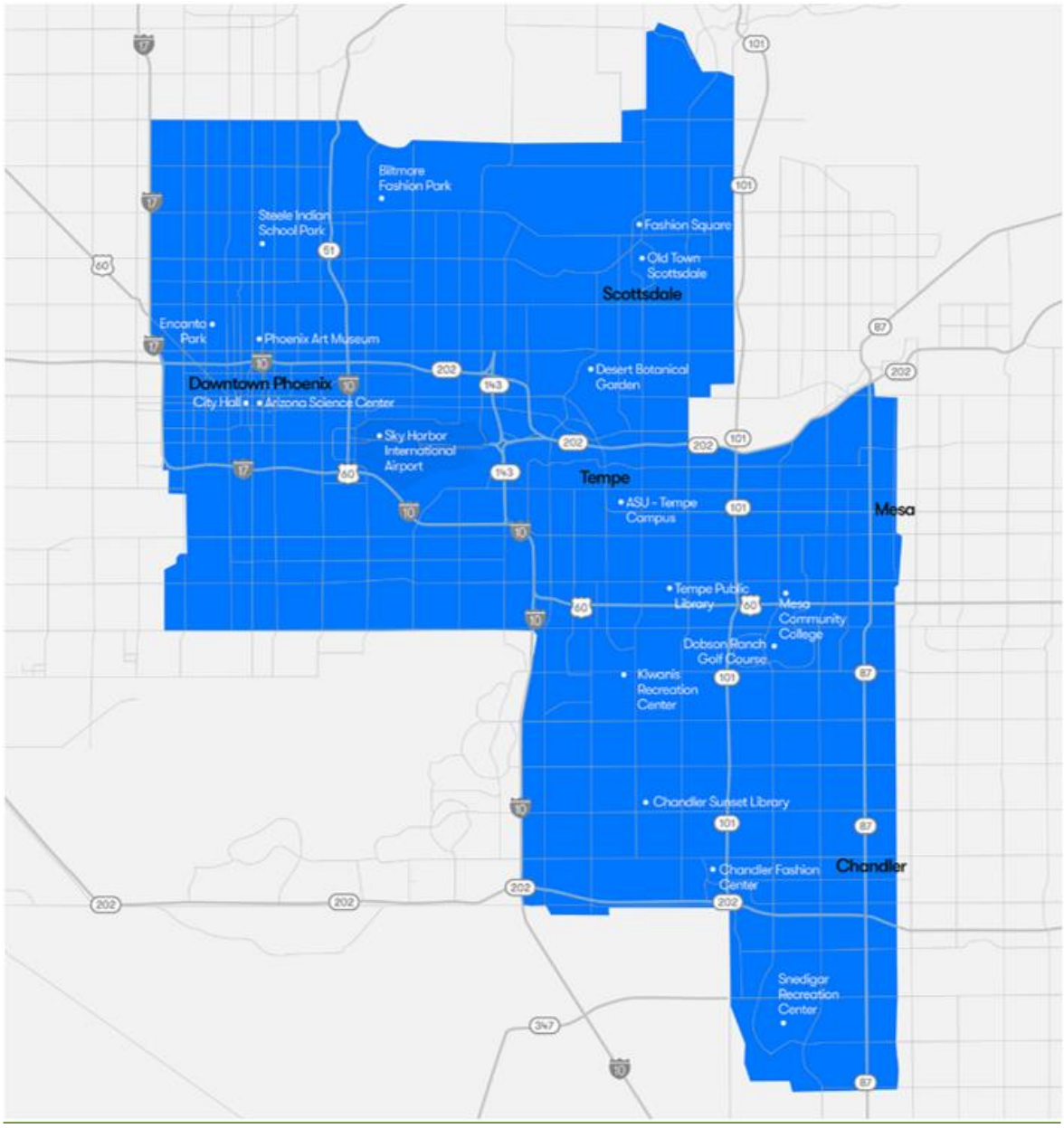

Figure 1. Waymo One operations area in Phoenix (source: Waymo)

3. LITERATURE REVIEW

A complete and comprehensive description of what supports Metro Phoenix ride-hailing service based on autonomous vehicles does not exist at all, either in stakeholders' official communications or in scientific papers. Therefore, the research was made through an extensive literature review in spread and unstructured information available on the several Waymo and other stakeholders' websites, in media articles and in some papers matching specific aspects of the existing Phoenix offer. This was important to support the modeling in *e³value*, identify the stakeholders and understand their relationship with Waymo and what type of value transactions they executed.

3.1 Modeling approaches

To this day there was no literature of any autonomous vehicles service modeled in *e³value*. Related research explored the modeling of autonomous vehicle businesses using agent-based and game-theoretic approaches analyze operations and understand market dynamics [21, 22]. It was important for this study to analyze other online business models to understand how to use this modeling approach. Nonetheless there are not many businesses modeled in e3value available for consulting, being this another limitation for our research.

3.2 Autonomous vehicles services

One of the main reasons that we choose Waymo to focus this study on is because of how they have shared information with scientific community. Waymo is not only the most developed autonomous driving technology company in the world as they intend to share information as much as possible with the community.

Waymo made available a perception dataset comprising high-resolution sensor data and labels for 1,950 segments. In March 2021, Waymo Open Dataset was expanded to also include a motion dataset comprising object trajectories and corresponding 3D maps for 103,354 segments. Waymo, therefore, aims to aid the research community in making advancements in machine perception and autonomous driving technology.

3.3 Safety and performance data

Waymo's official information also includes The Emergency Response Guide and Law Enforcement Interaction Protocol [23], and documents like Safety Report [24] and the Safety Methodologies and Safety Readiness Determinations. Waymo also shares papers like The Public Road Safety Performance Data [24] and Waymo Simulated Driving Behaviour in Reconstructed Fatal Crashes within an Autonomous Vehicle Operating Domain [23]. These information helped us comprehend how seriously Waymo has taken safety issues in the development of their technology, it has been their main focus since its creation.

Other studies focused on evaluating the safety and performance of shared autonomous vehicle services, analyzing technology reliability, how they interact with humans, and traffic flow impacts [20, 25]. Our research aims to provide insights for strategic decision-making, operational action, and verify the overall success of shared autonomous mobility services.

Most of the relevant information comes from Waymo's website [21, 22]. The company has been very keen on sharing the most information possible without compromising its own authenticity as an innovative company, protecting itself from giving away all the knowledge. On the other hand, as expected, some important information was only available by searching alternative sources, namely publications like Wall Street Journal, The Verge, The Drive, Electrek, Business Insider, Electronic Design, The Atlantic or even some MIT Lectures with Waymo Engineers as guests.

Waymo is very clear about further needed information for research projects, when it states on its FAQ "Everything we have to share is available on this website and on our blog, so they are the best places to look for details on Waymo. We can't provide any other information at the moment".

All this shared information partially supports the understanding of the concepts allowing the existence of Waymo ride-hailing service in Phoenix. Considering all the limitations of existing literature, datasets, and information sources and the lack of academic literature available, this study aims exactly to fill that gap, to provide study and investigation regarding the deployment and implementation of autonomous vehicles ride-hailing services.

Figure 2 presents each phase of the research methodology in detail, outlining the work that will be done in each stage.

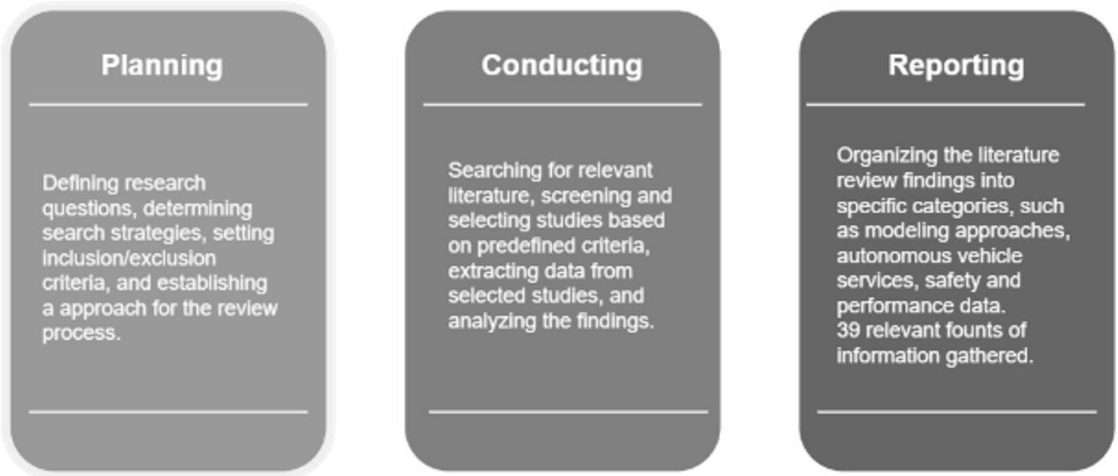

Figure 2. Literature review diagram

4. PHOENIX RIDE-HAILING SERVICE

The company started test-driving its cars in Chandler, Phoenix in 2017, and in October 2020 it launched a driverless ride-hailing program in the East Valley, that has recently reached 500,000 miles travelled in the area. In Arizona, people can already get Waymo One. The rides have been fully driverless. By early 2020, Waymo was serving between 1,000-2,000 Waymo One rides per week and 5-10% fully autonomous rides within their Trusted Tester program. This was a beta service that people used with limited services and resources, in order to help the company to develop the technology.

Based on available formal and informal information, it was possible to identify the various stakeholders and actors that are present in this ecosystem. Information provided by Waymo itself or its own partners through literature, articles, formal speeches [26] and interviews was vital to understand how all the actors present in the ecosystem interact and exchange value with each other.

As an Alphabet Inc. company, Waymo may not publicly reveal all the information regarding its business strategies, value networks, or specific partnerships. Some information may be restricted due to confidentiality agreements or competitive reasons, reducing the amount of information provided. Furthermore, the autonomous car market is fast expanding, and businesses such as Waymo are constantly refining their business models and value networks. As new developments and partnerships emerge, this dynamic nature might cause information to become outdated or incomplete.

When a business formalizes its operations, it is part of a network of companies exchanging value, a value network, that is represented in Figure 3.

In the proposed *e³value* model for the Waymo One Phoenix components in Figure 3, there is one partnership between two Alphabet companies, the actors Waymo and Waymo One. There are seven outside actors involved: Intel, Roush Enterprises, Phoenix Government, Trov Insurances, Avis, Bosch and Stellantis. And there still three market segments: Investors, Clients, and Satellite Providers.

In the following research we take a deeper look into each main actor and how it relates with the outside ones. This type of analysis will help us later understand the plans that Waymo has for the future as creator of Waymo One.

This first overview over the several Phoenix components is helpful to understand how Waymo and Waymo One are operating in this pilot project city. As until now, in this first phase, we modeled the ecosystem in the software through information, insights, documents and articles that were available.

We will go deeper into the Value Web that each partner is inserted on, in order to understand which are their needs and how are these outside actors helping for the value exchange.

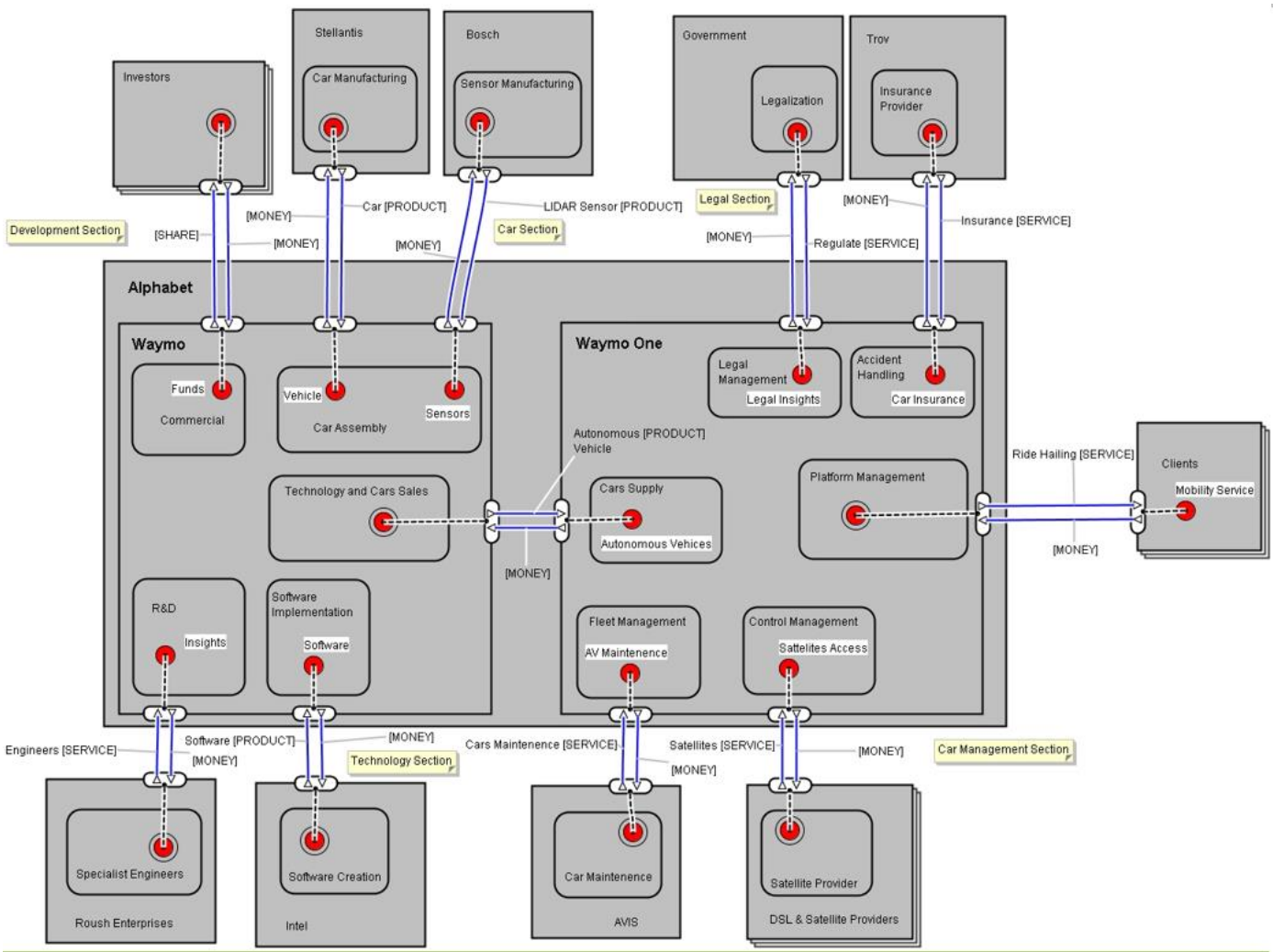

Figure 3. Proposed *e³value* model for the Waymo One Phoenix ecosystem

4.1 Waymo value network

Waymo currently has deals with car manufacturers such as Chrysler and Jaguar to use their cars. They produce most of the sensors and computing technology in-house with tailored deals with Bosch and Intel, which makes custom sensors and software for Waymo to install in their cars. This is particularly important in terms of future business strategy for the company, being able to adapt its own technology to different types of cars from different manufacturers and then provide it to a buyer (mobility provider), in this case Waymo One.

In the following Figure 4, we look closer to how Waymo executes its value transitions with other companies, the outside (partnership) actors, in order to be able to create, develop and implement its business values, so reaching the final goal of creating autonomous cars. This is considered the business model that provides the product.

The central actor, Waymo, exchanges value with four different actors. To help safely navigate the complexities of the road, Waymo's self-driving technology needs to see and identify what is around it. To perceive its surroundings, Waymo created its own technology called Waymo Driver, which relies on a powerful custom sensor suite of LiDAR, cameras and radars, while neural nets empower the self-driving system to understand the sensor data and respond to a wide range of scenarios [25]. This technology has been developed not only through inhouse intelligence but also with the help of partnerships created with two other outside actors: Roush Enterprises, an engineering consultant company working with Waymo since 2015 providing engineers and knowledge in the autonomous cars sector supporting directly the development of Waymo Driver, it has been also developing autonomous vehicles technology for other companies [27], Intel, that is a big partner of other companies of the group, which has been developing a custom-made software, providing car chips and sensor-data processing for Waymo since the launch of Google's [28]. As Waymo's self-driving technology becomes smarter and more capable, its high-performance hardware and software will require even more powerful and efficient computing. By working closely with Waymo, Intel is providing Waymo's fleet of vehicles with the advanced processing power required for autonomy levels 4 and 5.

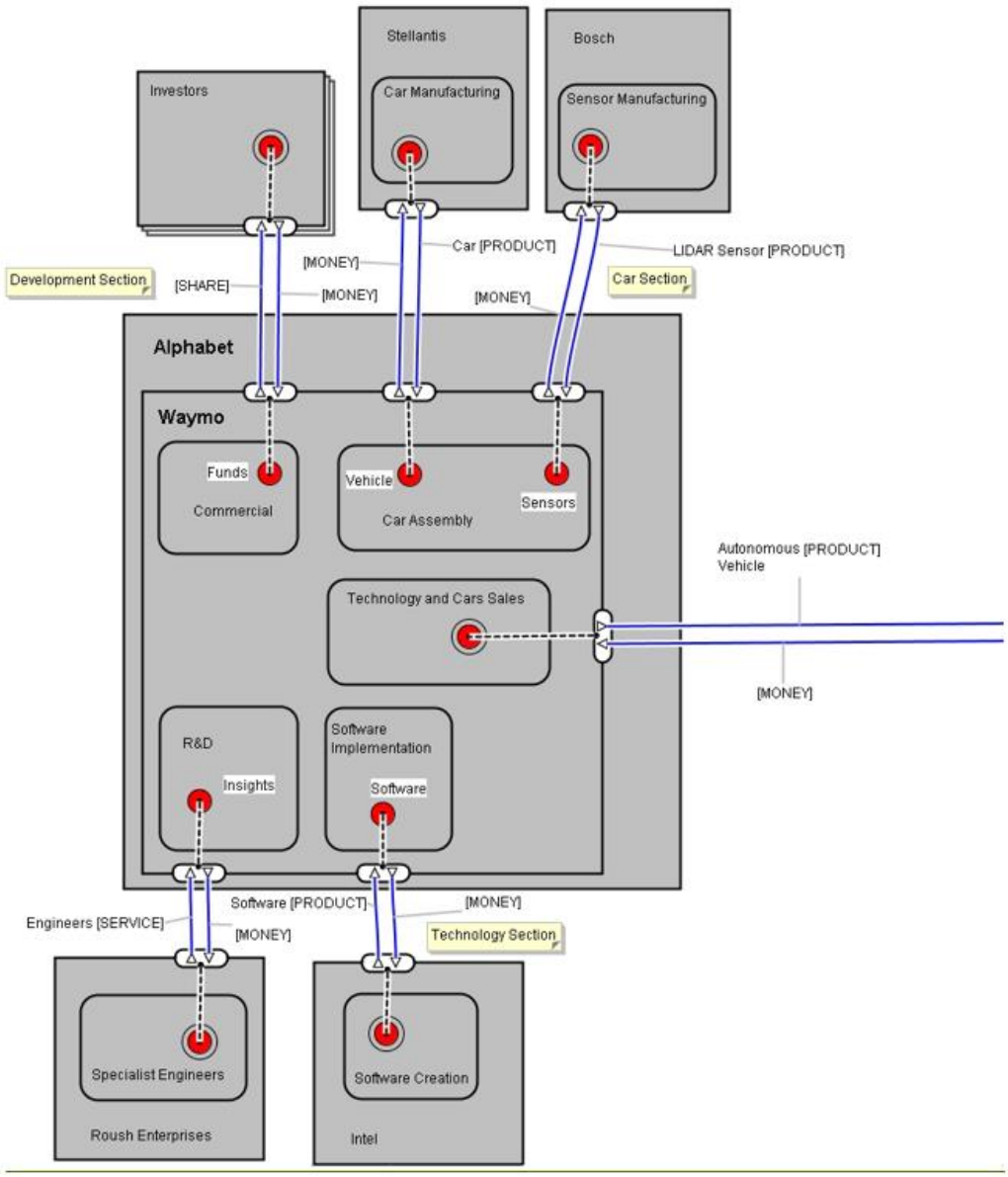

Figure 4. *e³value* model of Phoenix (Waymo actor close up)

In terms of hardware, Waymo has a big partnership with Stellantis, the manufacturer of the Fiat Chrysler Pacifica [29], that provides Waymo with the fleet operated in Phoenix. One of the great advantages of Waymo is the manufacturing of its own sensors and LiDAR's fitted in the cars, which is the main reason why Waymo is considered to be the leader in autonomous driving. Even though these sensors are overly complex and expensive, they are a significant improvement when compared to the cameras and sensors self-driving pack of Tesla, as stated by Rice [30]. A collaboration with Bosch helps Waymo build all of the sensors and LiDARs needed to put together the self-driving Pacifica [31].

In terms of market segments, Waymo exchanges value with Investors that fulfil the need for funding and investment. One of Waymo's investor partners is Magna International [11], that is one of the largest companies headquartered in Canada and the largest automobile original equipment parts supplier in North America. Like Magna, there are other societies of investment, one of them being Alphabet for obvious reasons, that fund Waymo's technology investigation, and in return for the invested money, Waymo releases shares of the company to these investors, creating the value transition seen in the previous *e³value* model.

4.2 Waymo one value network

After months of testing and millions of miles of developing self-driving vehicle technology, Waymo launched the country's first commercial autonomous ride-hailing service, the Waymo One, a spin-off that was created with the purpose of using its parent company autonomous cars to run this new business. The following image, Figure 5, is a representation of how Waymo One interacts through value exchange with outside (partnership) actors in order to run its ride-hailing service in a sustainable and optimal way.

In the present model, the central actor Waymo One is responsible for the ride-hailing service with Waymo's autonomous cars. It consists of a company that runs a platform that processes customers' requests, fleet management, control management, legal issues (legislations), accident handlings and cars supply.

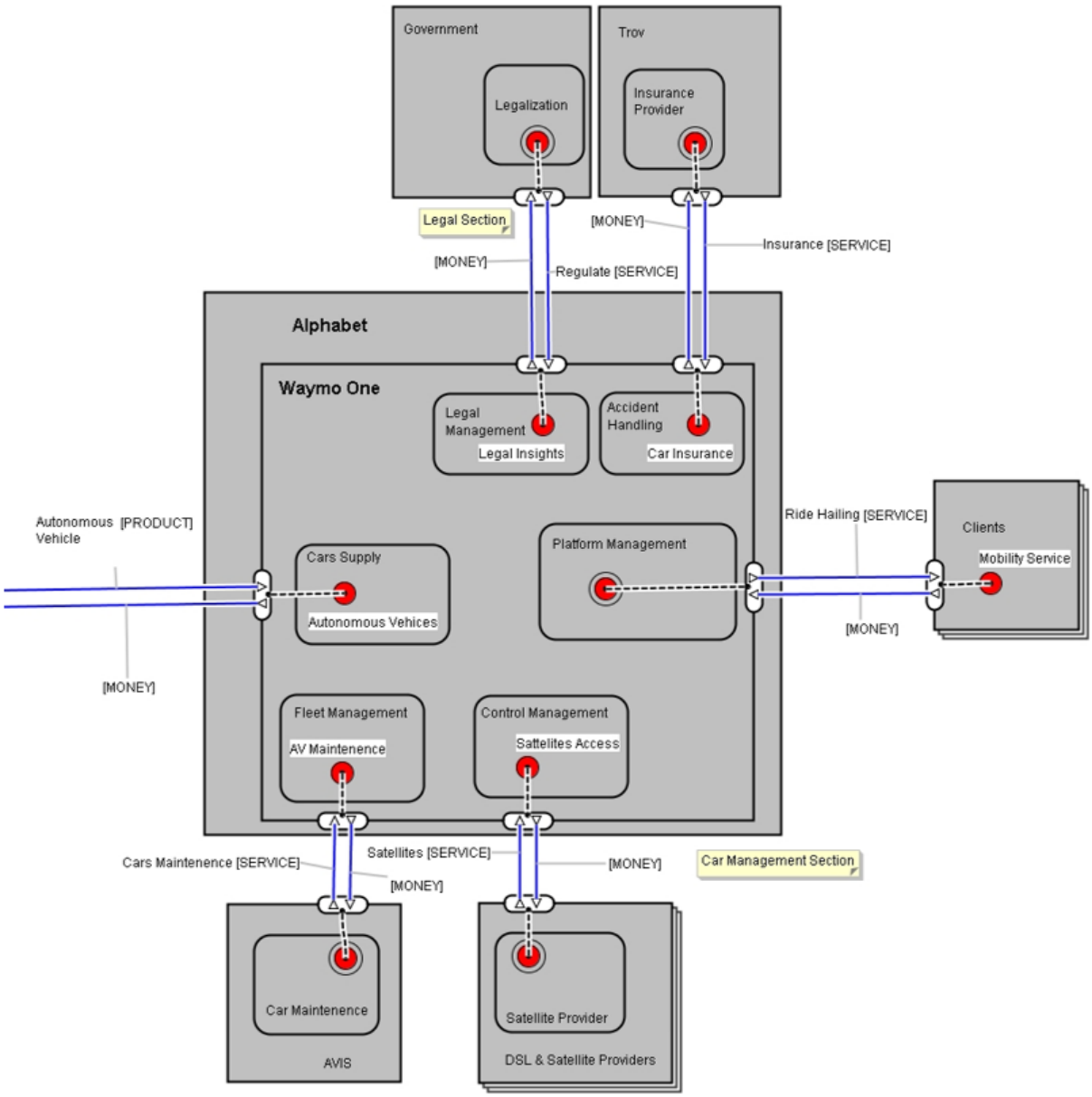

Figure 5. *e³value* model of Phoenix (Waymo One actor close up)

The value flow starts in the client, which has a need of going from point A to point B, wherever those locations are within Chandler designated area. This need is solved through the service provided by Waymo One. The customer needs to pay a fee and provides his personal data in exchange for the service. The payment is processed by the platform itself, that collects provided data from client's personal information and also the data gathered from the trip. As soon as the payment proceeds, the platform is going to communicate the nearest car to meet the customer, and then the trip starts.

Depending on what type of information the platform receives, there are signals that can be emitted through different value actions of the platform. If, by any chance, there is a problem with a car or an accident, the client can give that information through his phone, and accident follow-up actions are triggered. The platform is directly in contact with Trov [32], the insurance company responsible for Waymo cars for this matter.

In terms of fleet management, it is known that Waymo has a hangar where it keeps its cars. This is where the cars are s stationed when they need to be cleaned, charged, or refueled, get checkups to prevent breakdowns and get fixed when needed. All this maintenance is AVIS' responsibility [32]. It is important to note that an autonomous car needs more maintenance than a normal car due to the lack of presence of a human figure, especially preventive maintenance. These types of cars need not only normal maintenance, such as oil and brake pad changes, but also frequent checkups on the LiDARs, sensors and cameras that support the autonomous driving.

The Phoenix Government actor is responsible to legislate and regulate this service, in a continuous way. We must not forget what was stated in the beginning of this study, autonomous cars are still at an early stage in terms of their development, and due to the lack of human presence, there is a bigger social responsibility associated to it. As for all of this, governments reserve to itself a strict and continuous presence when controlling and legislating these services.

Trov is the insurance company responsible for providing insurance to the fleet of autonomous vehicles of Waymo, Trov is pioneering a cutting-edge approach to insurance that's ideal for ride-sharing because it's customized for every trip, being the perfect partner for Waymo [28].

The value exchange with the market segment of DSL and Satellite providers serves the need to control the fleet and also to collect data that is constantly shared with Waymo to support the development.

4.3 Waymo One value network

Conceptually, what has been done in Phoenix is a Value Network between two distinct companies. As previous highlighted, Waymo is responsible for developing the technology and applying it to the vehicles, creating its own autonomous vehicles. On the other hand, Waymo One is a company that provides a ride-hailing service in the city of Phoenix, which uses a fleet of autonomous vehicles provided by its parent company, Waymo. Even though the information about how these two companies is run is minimal, it is correct to assume their relation as a partnership between a supplier and a client, as it was modeled in Figure 6, representing the value that is exchanged between these two companies.

As referred before, Waymo is developing an Autonomous Driving Technology, called Waymo Driver, as well as all the sensors, LiDARs and cameras that are needed in an autonomous car. Waymo is also responsible for the application of this technology, as previously stated. Waymo One, on the other hand, pays Waymo for its product (car and technology).

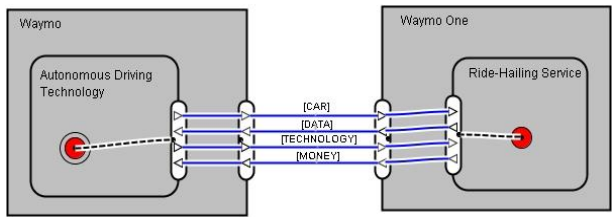

Figure 6. *e³value* model of partnership between Waymo and Waymo One

Waymo has kept this relation/partnership between Waymo and Waymo One very indoor, and so it is known very little about how exactly these two works with each other, how they interact or how much Waymo One pays for the cars, if indeed there is a payment. This makes it more difficult to extrapolate these scenarios to other markets and situations, since we do not have a clue of how much Waymo is charging for its autonomous vehicles. Such information would help this research since we would be able to use *e³value* to perform a profitability assessment and analyze the feasibility of this business model and future other investments that pretend to use Waymo Technology.

5. DISCUSSION

The *e³value* tool allowed us to perceive how the value actors exchange value with each other in order to reach a sustainable business model. It also allowed us to understand what is needed in order to reach a sustainable system to a similar business like this. By studying and analyzing all the information and insights gathered from this study, we can simulate and predict a business model for a ride-hailing service, using Waymo's autonomous cars, in other cities in the world. The great advantage of using *e³value* to model businesses is not only to understand how the value networks interact but also to use it as references for future businesses. As stated, *e³value* provides a mutual understanding of a business idea executed by a network of actors that jointly create, distribute, and consume value in inter-organizational business models, providing an overview of operations.

From the models it was clear to understand that Waymo tried to partner every type of companies that could provide complimentary products or services to development of the technology. Right now, the company focus all of its own resources developing the Waymo Driver and its implementation, everything else is outsourced through partnerships with leading companies in each sector. These companies also have high interest in being present in the initial phases of the development of these cars, making them ready and prepared for the future.

We believe that there are two perspectives of doing business in the shared autonomous mobility market: To develop the needed technology to implement in a mobility service, or to buy the technology already developed and implement it in a service of its business area, such as Uber or Lyft. This Waymo business study can help us understand both business paths.

5.1 Technology development and implementation

As acknowledged, Waymo is responsible for developing the technology and executing it through Waymo One. Although vehicles are not the business scope of Alphabet, the developing of the autonomous technology goes in hand with its value propositions of innovation, social awareness, and emissions reduction. It always has been the purpose of the group to be leaders in any technology field.

This path of business can be compared to what Tesla has been doing the past years. They have been developing their own selfless driving technology and implementing it in their own vehicles. For Tesla it makes sense to develop and implement all the knowledge gathered throughout the years once they are a company specialized in automobiles and innovative mobility. Unlike Tesla, Waymo does not have the facilities or the capability of manufacturing their own cars, parts and sensors, thus Waymo has the need to resort to other companies. From the outset this will always be a limitation in relation to the rest of the market segment.

On the other hand, Waymo is a company fully focused on the development of the autonomous technology, although the company does not develop its own cars, this has not been a problem for Waymo. Since the Google project car Waymo changed its strategic directions to develop a system that is implemented in normal vehicles. For this reason, Waymo as company only has one objective and that is to develop the best autonomous deriving system. In consequence Waymo right now is one of the best companies in the autonomous driving market while Tesla is considered to be dead last [33].

From the *e³value* model of Waymo, we can see that the value network involves value exchanges with many companies that provide hardware and software to the construction of the autonomous car. Waymo's role is to set up everything and through specialized labour and know-how develop the technology.

5.2 Technology purchase

Companies that already have a big presence in the mobility market prefer to buy this type of technology in order to increase their engagement with the clients. It is not profitable for a company that is specialized in mobility services to operate outside its area and develop a new technology, so it makes sense for these mobility companies to go to the market of autonomous vehicles and buy the product already developed. It is as simple as buying a product and monetize it through a service.

Literature says that large companies are no longer developing all the applications, at this point they work much more through partnerships with smaller companies that specialize in sub-segments. As stated by Doz [34], partnerships between larger and smaller firms have multiplied over the last few years. To large firms, partnerships usually offer a channel for tapping into the innovative and entrepreneurial potential of smaller companies, and for overcoming some of their own rigidities. In most of the observed partnerships, smaller firms perform research and development for, and/or transfer innovations to, the larger firms. These larger firms offer their smaller partners the ability to reach world markets quickly without having to build their own technology.

Waymo's former CEO John Krafcik stated in an event in New York back in 2018 [35] that their future focus is to improve the driverless technology through Waymo Driver and leave the rest of the car production and ride-hailing business to others in the industry. This is especially important because it sustains what we concluded from our investigation.

It is important to understand that Alphabet Inc.'s business scope is focused on investing and acquiring technology companies to profit from them in the future [36]. The literatures teach us that Alphabet is operating this way with its other companies. Google developed the Android, and phone manufacturers use the Android on their phones. Though Waymo has started to create ride-hailing services in a couple of areas, there is a possibility that the creation of the company will serve to validate and demonstrate its technology as a showcase to other companies.

Waymo is already partnering with Uber, the plan is for Uber being responsible for all the ride-hailing service while Waymo keeps on focusing and developing the technology [37]. This partnership will permit each company to focus on their specific business models, Waymo as autonomous car technology developer, and Uber as mobility provider. Both companies were fierce rivals not long ago, it started to turn very costly for Uber to develop a new and complex technology like this, being the partnership with Waymo the only path to transform its fleet into autonomous cars [38].

In Figure 7, we module a simple value network possible for the future of Waymo, modeled in *e³value*. It represents the business model that Alphabet Inc. is using with Android for example, which consists of Waymo continuing to invest and develop the autonomous driving technology, Waymo Driver, and then selling it to all types of market customers, such as ride-hailing services companies that already exist and operate, like Uber and Lyft, or to car manufacturers that do not have the capacity of developing this type of technology but see here a window of opportunity to enter the market of autonomous vehicles. Note that this technology was not only designed to serve a ride-hailing service, but it transforms lower autonomy levels into a level 5 autonomous car by just applying it. This means that the technology developed by Waymo can be seen as an application to normal cars. Anyone that has this technology can apply a "package" to a regular car and make it autonomous.

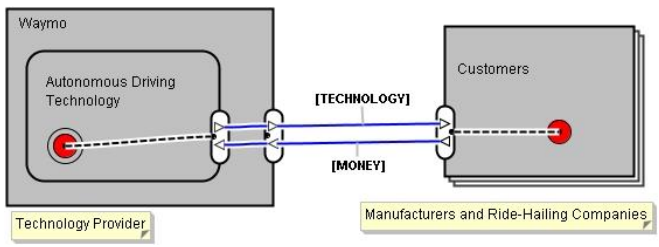

Figure 7. Proposed simple value network of future Waymo business modeled in *e³value*

The Waymo business study shows us that the company is developing and implementing the technology. The creation of Waymo One can be seen as a support to the research and development of Waymo itself. Having its own service where the technology is implemented, facilitate the information and data exchange that assists the program progress. The literature revealed that Waymo One was created with this purpose, and not to be a profitable company that will compete against other companies in the autonomous mobility market.

Waymo has also announced that it will partner with Uber

Freight in order to keep developing its autonomous trucks and support their deployment [39]. Waymo's self-driving trucks will focus more on logistics companies that want to convert or expand their fleet into autonomous driving. This once again shows how Waymo is committed to invest the technology itself so it can apply to all types of mobility solutions. The plan is for any type of mobility provider or dependent company to be able to implement autonomous driving in their business.

We can only assume what will be Waymo's next step in terms of its business plan for the future. It can continue to develop the technology while running a parallel ride-hailing service, that keeps close communication for support, or it can simply sell the technology to other mobility companies, and through partnerships keep the support to the development.

It is not our goal to predict what the disclosure will be, the aim of this paper is to model Waymo business in Phoenix to understand how and what do shared autonomous vehicles companies need to operate in an ecosystem.

6. CONCLUSIONS

This study illustrated how a value network has been implemented in Phoenix through the creation of ride-hailing of autonomous cars. The modeling of this ecosystem in *e³value* helped us understand how all the value actors interact with each other.

The *e³value* methodology has helped us understand what a company does, like Waymo One, needs to run a successful autonomous ride-hailing service. Modeling the business in *e³value* helped us identify all the stakeholders that need to be involved in a service like this, and what type of value each one of them exchanges. We were able to get a macro-overview of Waymo One operations and the key products and services it requires. This fulfills exactly what we aimed as research objective, to provide a comprehensive understanding of Waymo One's business model and its key drivers of success.

It is important to state that documentary sources research were limited to articles launched until May 2022, which means that any paper launched after that date can change the model, with the need of a new confrontation of the reference model with another real situation.

For the best of our knowledge, the value proposition of this research, which involves creating a reference model for the introduction of autonomous cars in Phoenix, is liable with some adaptations to be used for other different situations.

A reference model should be evaluated using different perspectives. In our case, for instance, listening to stakeholders about their eventual participation would bring important value in terms of model validation. That direct survey, as stated before, was not possible in Phoenix, and would acknowledge if the now improved model does make sense or not, if identified stakeholders should be part of the model or are needlessly, and if relationships among them are as represented in the reference model or not.

Finally, it is important to refer that one of the tools of the *e³value* software is the net value flow analysis of the value activities [4]. Studying this analysis in a market scenario as Phoenix would be interesting, nonetheless, it could not be done due to the lack of information provided or documented. However, this analysis still does not make sense at this point, once Waymo is still developing the technology and the ride-hailing service, being in a phase of hard investment and not yet profitable.

As referred before, we have information regarding all the interactions between the partnership and the outside actors, however all the value transactions that occur inside the partnership is kept as a secret turning impossible to study the economic flow of a business model between Waymo and a potential client for its technology. The *e³value* methodology is essential for analyzing complex socio-technical systems like shared autonomous mobility services. It provides a systematic framework to understand stakeholder roles, value exchanges, and system dynamics. It also helps to identify and optimize value creation, with risk assessment and mitigation, and also supports decision-making by evaluating different scenarios. Employing *e³value* can help stakeholders gain valuable insights, optimize system performance, and make informed decisions to create sustainable and efficient shared autonomous mobility services.

The creation of a separate organization, which runs the same way as its future clients (Uber, Lyft) makes it possible for Waymo to "showcase its product" to whoever wants to follow this path of industry. In a straightforward way, Waymo created the technology, then provided it to its own subsidiary who then assessed the business economic and operations sustainability. Result is a proven concept ready to be implemented.

Mobility providers that want to enter the autonomous mobility market need should embrace modeling approaches like *e³value* for a comprehensive understanding of the business ecosystem, invest in robust autonomous driving technology tailored for ride-hailing services, like Waymo's, foster partnerships to accelerate deployment, evaluate business viability through modeling prioritizing safety, and promote collaboration to ensure successful integration of autonomous vehicles into transportation systems.

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