A Model for the Deployment of Shared Autonomous Vehicles in Urban Areas Based on the Research Literature

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ABSTRACT

The deployment of Shared Autonomous Vehicles (SAVs) in urban areas is no longer a futuristic vision. Pilot projects are undeniable realities in various locations, and automakers research agendas are clear about this increasing autonomous trend. An ecosystem that supports the deployment of autonomous mobility is imperative, before this new type of mobility becomes a reality. Trying to understand what is absolutely essential in a city, to allow the operation of SAVs and to attract potential investors, is the aim of this research. This work started with a Systematic Literature Review (SLR), where the main concepts supporting SAVs were identified, and continued using a Topic Modeling approach, specifically Latent Dirichlet Allocation, to reach the most important topics and clusters, that were then modeled in ArchiMate into a possible ecosystem for the deployment of SAVs in urban areas. Finally, the reached model is confronted with a real case in order to establish a gap analysis between the theoretical reference model and what is already happening in Beijing. The result is an improvement of the reference model.

1. INTRODUCTION

In Phoenix SAVs are already becoming a reality. In fact, at this moment, there are pilot projects in a testing phase in several cities [1].

This testing phase is being fueled by the various stakeholders that are taking steps towards autonomous mobility. The inherent disruption this will create, which is considered here not as a technology problem, but as a business model [2], can bring enormous benefits to society, as identified in the selected literature that is the base of this research.

Related to that, Cavazza et al. [3] observed a study gap related to business models, which the authors confirmed in the SLR phase, where most of found articles were about purely technical features.

Right now, forecast changes are undoubtedly relevant. In fact, according to the study [4], research results in all fields indicate that both short-term and long-term implications of AVs are expected to be significant, including possible adverse effects. So, there is controversy regarding the effects of autonomous mobility.

Wadud et al. [5], researching energy efficiency, concluded that high levels of automation for vehicles can decrease or increase total road transport energy, with the ultimate outcome depending on the extent to which autonomous transportation reduces the energy intensity and energy demand of travel, versus increasing overall demand for travel due to convenience and participation of user groups such as the elderly and disabled.

On the other hand, Soteropoulos et al. [6] highlighted that although private AVs are mostly found to increase vehicle miles travelled and reduce public transport and slow modes share, shared automated vehicle fleets, conversely, could have positive impacts, including reducing the overall number of vehicles and parking space.

Just to present a significant example, the International Transportation Forum has realized a study in the city of Lisbon in 2017, which concluded that the results of replacing private car traffic with new shared mobility services represent 210 football fields of land that can be freed after eliminating unnecessary parking spaces. They also concluded that 90% of the vehicles currently used would no longer be necessary and, as such CO_2, emissions could be reduced by 27%.

The problem is that turning these test environments into a reality and spreading them all over the world will not be as simple as having an automaker produce and test Autonomous Vehicles (AVs). It goes well beyond that.

Beyond an automaker producing and testing the basic functionalities, such as perceiving the surrounding environment and making appropriate decisions in real time, using Artificial Intelligence (AI) [7], the urban areas where those cars will move will need to be adapted in order to accept this new type of mobility.

Therefore, the aim of our research is to understand the necessary elements of the ecosystem that a city or an urban area will need, in order to accept autonomous vehicles, i.e., which are the mandatory requirements to introduce them, if people accept this type of mobility. Hence, before we dive deeper into the type of ecosystem needed in order to support a driverless urban offer, we must emphasize people's acceptance. Although this is not the scope of our research, it is an important assumption for the success of any introduction attempt of a new mobility solution.

With the acceptance pre-requisite in mind, under the EU

Horizon 2020 Research and Innovation Program (https://h2020-trustonomy.eu/4-new-projects-on-the-european-horizon-of-the-autonomous-driving/), projects that focused on driver behavior and acceptance of connected, cooperative and automated transport have been supported.

As described, public authorities are quite concerned with the raise of autonomous mobility, allocating public funds in cooperation with private entities to research people's acceptance, which is the base for the success of the deployment of this new solution.

Besides that, relevant academic research has been published. Etzioni et al. [8] modeled the mode choice between automated and conventional vehicles using a mixed multinomial logit heteroskedastic error component type model. They found that large reservations towards automated vehicles exist in six researched countries, with 70% conventional private car choices and 30% automated vehicles choices. They also concluded that men under the age of 60 with a high income who currently use private car are more likely to be early adopters of automated vehicles.

Through an online survey in eight European countries, Kyriakidis et al. [9] reconfirmed the importance of safety on the acceptance of AVs. Spearman correlations show that age, gender, education level and number of household members have an impact on how people may be using or allowing their children to use the technology, e.g., with or without the presence of a human supervisor in the vehicle. Results on vulnerable road users show the same trend. The elderly would travel in AVs with the presence of a human super- visor. People with disabilities have the same proclivity, however their reactions were more conservative. Next to safety, reliability, affordability, cost, driving pleasure and household size may also impact the uptake of AVs.

Finally, Feys et al. [10] compared the results of two pilots with different target groups in the same city through an online survey after passengers had experienced a ride. Results showed that more than 70% of the passengers expressed no concerns with regards to autonomous vehicles, and majority had a positive experience with an autonomous shuttle and evaluated it positively in terms of driving behavior, entry and exit and comfort. The regression analysis indicated that enjoyment of the ride is an important factor that contributes to the intention to use autonomous shuttles in the future.

The idea of the present research is the creation of a possible model for a SAVs ecosystem. A model that can then be instantiated and used everywhere, sup- porting both political decision makers and investors in their urban mobility strategical options. Naturally, considering region diversity, SAVs will require tailoring to local contexts for safe and efficient operation that will allow them to earn the trust of users [11]. Moreover, according to the same authors, cultural nuances in personal transportation will make ride sharing a business that is service first and technology second, with significant tailoring to local context required.

In order to reach this model, we started by performing a SLR, through which we identified 120 documents that corresponded to our focused subject. Then, supported by the fact that topic models are attractive because they discover groups of words that often appear together in documents [12], we used a Topic Modeling approach, in order to identify the words/ topics that better characterized such an ecosystem. After that, those words were grouped and then matched to ArchiMate Layers and Sub-Layers, enabling us to obtain a possible model, which includes the various stakeholders and their interactions, supporting shared autonomous mobility. Finally, that model is compared with a real situation, with the aim of being validated and improved.

This paper is structured as follows. In Section 2 we will start presenting the research, which includes an SLR, Topic Modeling, Word Similarity and Word Grouping. In Section 3 we continue presenting our research, with the steps to build an ArchiMate model, as well as the resulting model, on Subsection 3.1 and the explanation of the model on Subsection 3.2. In Section 4, we enlighten the main concepts behind Beijing SAV and demonstrate and evaluate the reference model. In Section 5, we present the lessons learned and the main contributions of this work. Lastly, In Section 6 we present our conclusion, including weaknesses, future research and the first effects of the COVID-19 pandemic.

2. RESEARCH METHODOLOGY

2.1 Systematic literature review

A Systematic Literature Review (SLR) is a means of identifying, evaluating and interpreting all available research relevant to a particular research question, or topic area, or phenomenon of interest. It aims to present a fair evaluation of a research topic by using a trustworthy, rigorous, and auditable methodology [13].

This SLR is based on Kitchenham's Procedures for Performing Systematic Reviews, which has the following three steps [13].

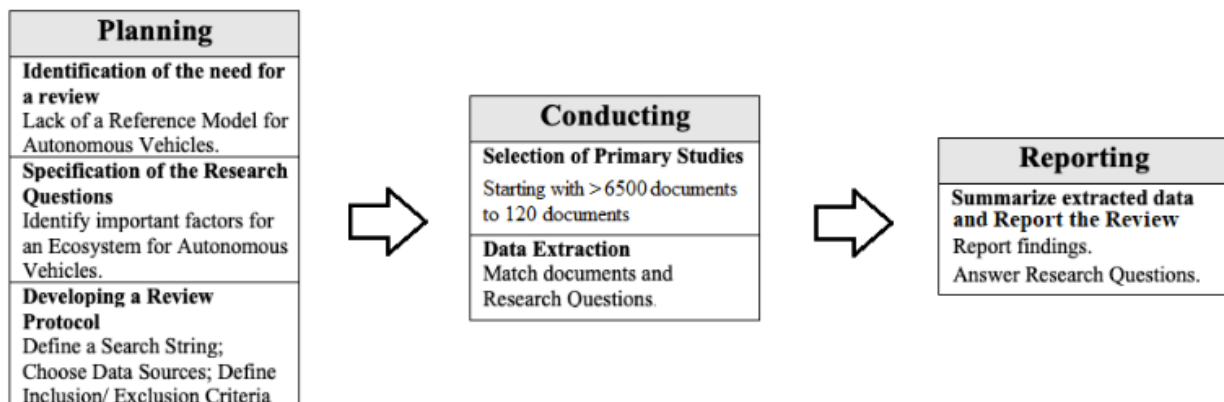Figure 1 represents these three steps adapted to our research.

Figure 1. SLR adapted to this research

SLR was chosen as the Research Methodology since our objective was to summarize the existent information on the subject of Modeling Ecosystems for Autonomous Vehicles and answer the specified Research Questions.

From our Systematic Literature Review (SLR) we were able to reach a final set of 120 documents, that focused on the search string topics, and from those documents we were able to get information regarding the main concepts needed to deploy SAVs in urban areas.

The reached results are not surprising since, as referred by the study [14], AV research is heterogeneous and registered a growing demand over time.

There are 120 documents [15-134] that were then used for topic modeling.

2.2 Topic modeling

Topic modeling is a statistical technique for revealing the underlying semantic structure in large collection of documents [135].

In this section we will present the topic modeling steps of this research, according to the study [136], which correspond to Steps 1 to 4, on Table 1. We will also present the steps preformed to prepare our final set of words to be modeled in ArchiMate, which correspond to Steps 5 to 8, on Table 1.

Table 1. Research steps after the SLR

Step	Activity	Section
1	Gather the 120 documents	2.1
2	Prepare the documents to be loaded in the software	2.1
3	Run 20,000 iterations	2.1
4	Get Top Words and Topic List	2.1
5	Remove duplicates and non-related words	2.1
6	Calculate similarity between words	2.2
7	Remove similar words	2.3
8	Concepts	2.4
9	Classify words in ArchiMate Layers and Sub-Layers	3
10	Model words in ArchiMate	3

One example of topic modeling is Latent Dirichlet Allocation (LDA). LDA can be described as a generative probabilistic model for collections of discrete data such as text corpora. It is a three-level hierarchical Bayesian model, in which each item of a collection is modeled as a finite mixture over an underlying set of topics. Each topic is, in turn, modeled as an infinite mixture over an underlying set of topic probabilities. In the context of text modeling, the topic probabilities provide an explicit representation of a document [13].

After gathering all the 120 documents, they had to be prepared to be used on Mimno's jsLDA (javacript LDA) web tool [136].

The jsLDA web tool is a user-friendly web-based implementation of LDA in javascript language, which offers instant presentation of results accompanied by a graphical view, giving the opportunity to the user to have a clear overview of the experiment [137].

To prepare the documents for upload, the corpus of each document was transformed into a single line and copied to a single file.

After all documents were copied to the file, they were uploaded to jsLDA. The "Document Smoothing" and "Word Smoothing" parameters were set to their default values of 0.1 and 0.01 respectively. We also set the number of topics to the default 36, and each topic to 10 words. Finally, we set up a "Stoplist", containing a list of stop words, such as "but" and "or", which was also uploaded to jsLDA.

Then, we ran 20,000 iterations, since that was the value at which we found the results to be more consistent, meaning that after that number of iterations the values remained unchanged.

Table 2. Excerpt of top 500 words

Word	Frequency
vehicles	4685
vehicle	3697
cars	2324
mobility	2062
driverless	1905
data	1896
traffic	1774
car	1655
transportation	1591
technology	1560
automated	1328
parking	963
urban	961
automation	838
connected	801
infrastructure	773
network	707
smart	579
communication	567
self-driving	508
sensors	463
automotive	413
sharing	396

Table 3. Excerpt of the raw 360 words extracted from the topic list

authorities
authorities
authorities
automaker
automakers
automated
automated
automation
automation
automation
automation
automobile
automotive
automotive
automotive
autonomously
autonomy
autonomy
autonomy
autopilot
autopilot
bao
bikeshare
bikesharing
bluetooth
brito
bumps
caliskan
camera
camera

At this stage, we were able to reach two different results: a list of the top 500 words that were used more frequently in all the documents, of which a list of the top 20 is presented on Table 2, and a Topic List, containing 36 topics with 10 words each.

Considering that, in topic modeling, a topic provides an explicit representation of a document (in this case a set of documents), we considered that the 360 words that form the 36 topics (36 topics of 10 words each) are the words that best represent our set of 120 documents. An excerpt of those 360 words is presented on Table 3.

It is important to refer that the resulting set of 360 words was still "raw material", meaning that there were many duplicate words as well as non-related words that had to be removed. After removing the referred duplicate and non-related words, we reached a set of 150 words.

2.3 Similarity

At this stage, we had a set of 150 words and, in order to verify if all those words were relevant to our model, we decided to calculate the similarity between them. This way, we would be able to remove similar words and maximize the chances of reaching a completely relevant set of words.

We then created a Similarity Matrix, where we placed all 150 words across the rows and columns.

To calculate the similarity between words, we used the Wu and Palmer (WUP) semantic similarity measure [138],

implemented by the WS4J tool (https://ws4jdemo.appspot.com).

According to the study [139], the WS4J tool provides a pure Java API for several published semantic relatedness/ similarity algorithms for WordNet Search 3.1 (WNS), which is a large lexical database of English, developed by Princeton University [140].

In some cases, where the similarity could not be calculated directly because one of the words (or both words) were not on WNS, we used the root words. Also, we removed multi-word expressions (such as "robot-taxi"), if they could not be found on WNS, since, if decomposed in their root words (in this case "robot" and "taxi"), they would not maintain the same meaning. In these last referred situations, we also tried (unsuccessfully) calculating the similarity using Google "word dumps" together with Gensim (https://radimrehurek.com/gensim/).

After calculating the similarity between all words, for each case of two different words that had a similarity level of 1 (between 0 and 1, being 1 the highest similarity level), we were able to remove one of them. The method we chose to select the word that should stay on our model was to check the previously referred list of the top 500 words (excerpt presented in Table 2) and to select the word that was more frequently used.

Finally, after removing similar words, we were able to reach a final set of 83 words. An excerpt of the final Similarity Matrix (of 83×83 words) is presented on Figure 2.

	authorities	automakers	automation	autonomy	autopilot	cameras	car	car-pool	carsharing	client	...
authorities	1,00	0,63	0,71	0,56	0,80	0,55	0,55	0,67	0,02	0,84	
automakers	0,63	1,00	0,35	0,33	0,30	0,20	0,20	0,59	0,29	0,24	
automation	0,71	0,35	1,00	0,67	0,78	0,84	0,74	0,43	0,05	0,70	
autonomy	0,56	0,33	0,67	1,00	0,56	0,22	0,22	0,40	0,06	0,27	
autopilot	0,80	0,30	0,78	0,56	1,00	0,74	0,74	0,35	0,14	0,80	...
cameras	0,55	0,20	0,84	0,22	0,74	1,00	0,70	0,24	0	0,67	
car	0,55	0,20	0,74	0,22	0,74	0,70	1,00	0,24	0,14	0,67	
car-pool	0,67	0,59	0,43	0,40	0,35	0,24	0,24	1,00	0,36	0,29	
carsharing	0,02	0,29	0,05	0,06	0,14	0	0,14	0,36	1,00	0	
...					...						

Figure 2. Excerpt of the final 83×83 Similarity Matrix

2.4 Concepts

After have reaching the final set of 83 words, we grouped them in Concepts, according their meaning and context.

Table 4. Concepts – Part 1

Word	Concept
automakers	automakers
vehicle	car
car	car
automation	autonomy
autonomy	autonomy
self-drive	autonomy
cameras	Vehicle detection and positioning hardware
laser	Vehicle detection and positioning hardware
lidar	Vehicle detection and positioning hardware
radar	Vehicle detection and positioning hardware
gpsheightsensors	Vehicle detection and positioning
sonar	hardware Vehicle detection and positioning hardware
car-pool	car-pool
carsharing	carsharing
ridesharing	ridesharing
client	client
travellers	client
server	IT Support Infrastructure
cloud	IT Support Infrastructure
communication	V2X
telecommunication	V2X
connections	V2X
internet	V2X
connectivity	V2X
network	V2X
interconnection	V2X
data	data
databases	data
e-mobility	e-mobility
electricity	e-mobility
energy	e-mobility
environment	e-mobility

In this research we are looking for a model that represents an ecosystem of essential stakeholders and components for the deployment of autonomous mobility in urban areas so, having that in mind we were able, at this stage, to identify each ecosystem element, most of the times as a group of more than one word.

Table 5. Concepts – Part 2

Word	Concept
fare	fare
fee	fare
firms	firms
fleet	fleet
fraud	fraud
roads	physical infrastructure
facilities	physical infrastructure
infrastructure	physical infrastructure
garage	physical infrastructure
drop-off	physical infrastructure
pickup	physical infrastructure
crosswalk	physical infrastructure
park	physical infrastructure
parking	physical infrastructure
insurance	insurance
insurers	insurance
premiums	insurance
metropolitan	metropolitan
authorities	norms
government	norms
municipality	norms
law	norms
political	norms
legality	norms
norms	norms
policy-makers	norms
regulations	norms
lawmaker	norms
researcher	researcher
privacy	privacy
protocols	vehicle protocols
moral	vehicle protocols
ethics	vehicle protocols
security	security
telecom	telecom
traffic	traffic
traffic-jam	traffic
transportation	mobility
mobility	mobility
rides	mobility
commute	mobility
computation	vehicle AI platform
autopilot	vehicle AI platform

Table 4 and Table 5 present the 83 words mapped to the final 29 Concepts.

3. PROPOSED ARCHIMATE MODEL

In this section we will present the ArchiMate modeling steps and their result, which correspond to steps 8 and 9, on Table 1.

3.1 Reaching a model

The next step was to classify all 29 Concepts into ArchiMate Layers and Sub-Layers, using the ArchiMate 3.1 Specification [141]. Table 6 presents the match between the 29 Concepts and the ArchiMate Layers and Sub-Layers.

After classifying the Concepts, we used Archi – Open Source ArchiMate Modeling (https://www.archimatetool.com) to model them as well as their relationship with each other, according to ArchiMate Relationships [141].

Table 6. Concepts matched to ArchiMate Layers and Sub-Layers

Concept	Layer	Sub-Layer
automakers	Business	Actor
car	Technology	Function
autonomy	Technology	Process
vehicle detection and positioning hardware	Technology	Device
car-pool	Business	Service
carsharing	Business	Service
ridesharing	Business	Service
client	Business	Actor
IT support infrastructure	Technology	Device
V2X	Technology	Node
data	Strategy	Resource
e-mobility	Implementation & Migration	Deliverable
fare	Business	Object
firms	Business	Actor
fleet	Strategy	Resource
fraud	Business	Process
physical infrastructure	Strategy	Resource
insurance	Business	Product
metropolitan	Business	Interaction
norms	Implementation & Migration	Work Package
researcher	Business	Actor
privacy	Business	Contract
vehicle protocols	Implementation & Migration	Work Package
security	Business	Function
telecom	Business	Actor
traffic	Business	Interaction
mobility	Implementation & Migration	Deliverable
vehicle AI platform	Technology	Process
wifi	Technology	Node

It is important to refer that we classified the word "car" as a device because we consider that modern vehicles (and specifically cars) are, in fact, computers on wheels [142].

The resulting model is presented in Figure 3. It intends to systematize a possible ecosystem for SAVs in urban areas, and all the essential elements for the deployment of SAVs, as well as the relations between them, such as the relationships between policy-makers, moral and legal procedures, between firms, services, fleets and fees or between the hardware, software and infrastructure needed to create AVs, operate them and maintain connection with them and amongst them.
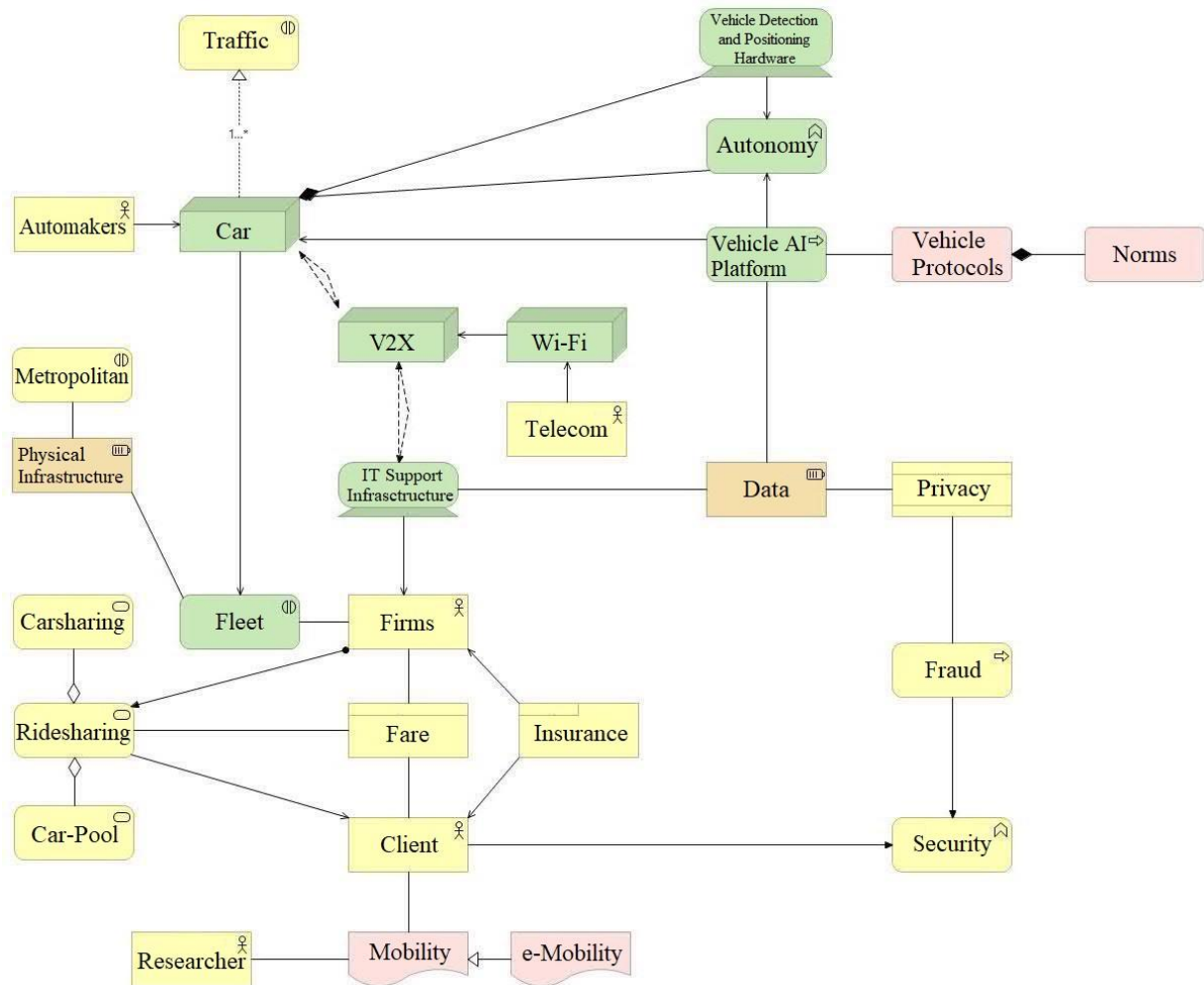
Figure 3. ArchiMate reference model to reach a possible ecosystem

3.2 Model description

The model presented in Figure 3 is the overall presentation of the various found stake- holders and elements as well as the relationships among them. It aims to represent the needed ecosystem to support SAVs, that is, what should exist in order to deploy such mobility concept in urban areas.

The way the elements are arranged was a choice of the authors and it could have been done differently (the idea was to show the model in a readable manner). On the other hand, the presented elements were not the authors' decision, but in turn, the result of the described methodologies.

The scope of this work is shared autonomous solutions in urban areas, and the reached model presents the determinant elements to have a structured offer. There is not a single central element, although "firms" (here understood as the autonomous mobility provider), the "car" and of course the "client" (or end user), are all central and connected in several ways with remaining elements.

It is important to refer that in this predictive model, which is partially based on optimistic reality and will afterwards be confronted with reality, Vehicle-to-Vehicle and Vehicle- to- Infrastructure connections (both included in "V2X") are available, providing the car with essential inputs for its operation. This means that the car is not only "intelligent" but it is also sourced by continuous information from the other cars and from the urban area infrastructure.

Some concepts, such as "telecom", "insurers" and "automakers", are providers, and other elements, such as "physical infrastructure", "norms" and "traffic" are con- textual, i.e., something that exists in a SAV contextual deployment.

Regarding relationships, the idea was to try to keep them as simple as possible. For example, of course there is a relation between the "researcher" and "insurance", but that would be an indirect relation, existing even before the deployment of SAVs, so it was skipped, in order to reach a cleaner and "easy to read" model.

"Metropolitan" areas must have the necessary "Physical Infrastructure", that allows "Cars" to operate. These Cars are operated by "Firms", in "Fleets", and as such they need "Insurance". The Operating Firms charge "Fares" to the "Client", in order to provide the service of "Mobility" ("e-Mobility" in most cases), using the concept of "Ridesharing", which includes both "Carsharing" and "Car-Pool".

There is a relation between "Vehicle detection and positioning hardware", "Vehicle AI platform" and "Autonomy", since both first concepts are needed in order to implement the desired level of Autonomy. In the same way, there is a relation between "Vehicle AI platform" and "Vehicle Protocols" since the last concept is used on the first. Also, "Vehicle Protocols" are based on "Norms".

The concept of "V2X" is used to allow "Cars" to communicate (using "Telecom" companies) with the "IT support infrastructure", which is part of the operating "Firms", and is used to keep important "Data", such as "Client" Data.

This Data is stored with the necessary levels of "Security" so that "Fraud" situations may be prevented and high "Privacy" levels are kept.

4. EVALUATION

4.1 Beijing

After presenting a reference model based on scientific research, which is a predictive scenario of a possible future ecosystem supporting a ride-hailing service, based on autonomous vehicles, it is important to demonstrate that such a reference model may in fact work.

A purely theoretical model, with no real-life application lacks contribution value. For that reason, the authors researched real examples of such an offer, and decided to focus primarily on what was identified in Beijing, China since it not a pilot-project, like several existing ones, but instead a real commercial offer.

4.2 Why Beijing?

As referred before, there are already locations where people can take an autonomous cab. An example is the city of Beijing, China, specifically in the Winter Olympic Games area, where service is provided by Baidu.

Baidu is the dominant internet search engine company in China. Its features and services are similar to those of Google, but its focus is on China, where it controls most of the search market.

According Wang Chong, Chief Brand Officer of Baidu Intelligent Driving Group, backed by the company's solid foundation in Artificial Intelligence, Baidu provides a safe, intelligent and efficient autonomous driving technology system, from fully driverless operation to large-scale commercial operation.

It is public that customers can access fully shared autonomous vehicles in three Chinese cities, namely Beijing, Wuhan and Chongqing. After receiving the permit, Baidu became the first provider of fully driverless autonomous ride-hailing services in the capital city of China, without a driver in the car, which was the main reason why the authors decided to choose the Beijing case.

There is not a source presenting the ecosystem that allows the existence of Beijing's ride-hailing service, which led to authors researching on the available publications what is behind Beijing's service, with the aim of identifying the main concepts that sustain the Baidu Apollo ride-hailing service offer.

The focus of the scientific literature concerning Beijing trial is generically the technical side of autonomous mobility. The studies [143, 144] are examples of existing research.

Therefore, with the support of the referred documents and strongly based on widespread information found on publications like Motorauthority, Yicaiglobal, Caix- inglobal, Zdnet, Prnewswire, Just-auto or Abcnews, as well as based on the data shared by the automaker FAW and (specially) by Apollo, it was possible to establish the main concepts that allow this type of service in Beijing.

Table 7 presents the several mentioned concepts.

Once the main Beijing concepts were identified, it was possible to move on to a gap analysis between those concepts and reference model concepts.

Table 7. Concepts of Beijing ride-hailing service

Concept
FAW
Hongqi E Concept
Level 4
Baidu/ Appolo Go
Fleet of 10 vehicles
Appolo Hardware Development Platform (Lidar, Radar, Cameras, Navigation, IPC, CAN, ASU, AXU, ACU)
Software is Appolo Computing Unit
V2X
Baidu Appolo HD Map
Appolo Game Engine Based Simulation
More than six million miles of testing, public trials also up and running in the Yizhuang, Haidian and Shunryi areas.
Baidu Shanxi Cloud Center
Baidu Cloud
510km of autonomy
Operating in Beijing's Shougang Park
The local authority is Beijing's Transport Commission
Ride-hailing service
Customers can be any person within designated area through an app
Fixed fee CNY30 (US $4.60) per ride
Client Interface is the Apollo Go App, QR code and health code
8 pickup and drop-off stations
Emergency through 5G Remote Driving Service, one person seating in rear seat
44 internet providers in Beijing area
Swiss Re is insurance provider
Cybersecurity through Integrated solutions, products, services and laboratory, including partners
One person seated in the rear seat for safety reasons
Legal authorization to operate is the T4 license

4.3 Gap analysis

At this stage, the authors attempted to understand if each concept on the reference model has a concept counterpart in Beijing.

Therefore, Table 8 establishes a match between the theoretical model and what was possible to identify in Beijing's reality.

Table 8. Gap analysis between theoretical model and Beijing's reality

Beijing Concepts	Gap?	Aggregated Group Words
FAW	No	Automakers
Hongqi E Concept	No	Car
Level 4	No	Autonomy
Baidu/ Appolo Go	No	Firms
Fleet of 10 vehicles	No	Fleet
Appolo Hardware Development Platform (Lidar, Radar, Cameras, Navigation, IPC, CAN, ASU, AXU, ACU)	No	Vehicle detection and positioning hardware
Software is Appolo Computing Unit	No	Vehicle AI platform
V2X	No	V2X
Baidu Appolo HD Map	Yes	
Appolo Game Engine Based Simulation	No	Data, Researcher
More than six million miles of testing, public trials also up and running in the Yizhuang, Haidian and Shunryi areas.	No	Data

Baidu Shanxi Cloud Center	No	IT Support Infrastructure
Baidu Cloud	No	IT Support Infrastructure
510km of autonomy	No	E-mobility
Operating in Beijing's Shougang Park	No	Metropolitan
The local authority is Beijing's Transport Commission	No	Norms, Protocols
Ride-hailing service	No	Ridesharing
Customers can be any person within designated area through an app	No	Client
Fixed fee CNY30 (US $4.60) per ride	No	Fare
Client Interface is the Apollo Go App, QR code and health code	Yes	
8 pickup and drop-off stations	Partial	Physical Infrastructure
Emergency through 5G Remote Driving Service, one person seating in rear seat	Yes	Security
44 internet providers in Beijing area	No	Telecom
Swiss Re is insurance provider	No	Insurance
Cybersecurity through Integrated solutions, products, services and laboratory, including partners	No	Privacy, Security, Fraud
One person seated in the rear seat for safety reasons	No	Security
Legal authorization to operate is the T4 license	No	Norms, Vehicle Protocols
	Yes	Car-pool
	Yes	Carsharing
	Yes	Traffic
	Yes	Mobility
	Yes	Wifi

In a high-level view, there are not many gaps, which might suggest that there is a significant correspondence between the reference model and Baidu's Apollo ride-hailing service. Notwithstanding, there are mismatches that need to be analyzed, there are concepts in the reference model that were not identified in Beijing and there are concepts found in Beijing that do not exist in the reference model.

4.4 Baidu Apollo HD map (found in Beijing)

In the reference model, vehicles use LiDAR and all the other sensors to know their surroundings. They are also connected with other vehicles (V2V) and with the city infrastructure (V2I). This means that vehicles move based on historical data managed with AI, receiving inputs from sensors, from other vehicles and from the infrastructure. The reference to the mapping of the area where vehicles operate was not identified in research method, which is the opposite of what was found in Beijing, where the area was exhaustively mapped in order to allow vehicles to circulate, establishing if there are differences between what was mapped and what is perceived in each moment. For instance, if a pedestrian is in the middle of the street, that is a difference in comparison with the accurate mapping done before by Baidu Apollo, and therefore vehicle understands immediately there is something wrong, avoiding a trampling.

4.5 Physical infrastructure (partially found in Beijing)

It was not found in Beijing any reference related with a garage, car cleaning and daily preparation or a charging place. Does that mean those structures do not exist? Of course not, those are mandatory requirements that surely exist. However, the authors found pick-up drop-off locations, which means that in Beijing origin and destiny points are fixed.

4.6 Apollo Go App, QR code and health code (found in Beijing)

The access to the ride-hailing service in Beijing is done through an app, which was not identified in the reference model, although nowadays it can be inferred that an app or something similar will exist for sure. What was not definitively found in the reference model is that the app creates a QR code, adding the customer's health data, and only after clearing the sanitary security will the car be unlocked and trip start. This gap is natural, because this security measure is a reaction to the Pandemic, and the majority of papers that sourced the reference model are from dates before the Pandemic. Nevertheless, it is a concept that should be considered from now on.

4.7 Emergency through 5G remote driving service, one person seated in rear seat (found in Beijing)

In Beijing, there is now one person seated in rear seat, which brings confidence to customers in an introduction phase. Does that mean that person will continue forever in Beijing ride-hailing offer? Surely not, which means that even though it was never identified in the reference model, the existence of that person is not a gap. Regarding the capacity of driving remotely the car, in case of need, that was not found in the reference model and that is a gap, because it is a security measure that not only brings confidence to customers but also avoids further problems if there is an incident on the road and the vehicle does not have the capacity to circulate. In such a case, Baidu Apollo can bring the car remotely to a safe location and solve the problem, which is an advantage vis-`a-vis the reference model.

4.8 Car-pool (found in reference model)

The reference model identified car-pool as a possibility. Considering that Car-pool by definition is the simple practice of different individuals coming together to use a single car for the commute, the concept here would be a different type of sharing, such as a person that owns an AV and shares that AV with other people. This is possible in principle, and it is neither denied nor confirmed by Beijing example.

4.9 Carsharing (found in reference model)

In Beijing, Baidu Apollo offers a ridesharing service, not a carsharing service. Carsharing is usually when the vehicle itself is shared amongst many people whilst, on the other hand, ridesharing is about sharing the route, rather than the vehicle.

Therefore, like car-pool, is possible in principle, and Beijing does not confirm or reject it.

4.10 Traffic and mobility (found in reference model)

The reference model has also these two group words, which are somehow related. Traffic also includes traffic-jam, and mobility comprises transportation, rides and commute, besides

mobility itself.

In fact, although not mentioned in the raised concepts of Beijing, those are implicit concepts included in other identified concepts that do not add anything new to the reference model.

4.11 Wi-Fi (found in reference model)

This concept is related to mobile data (on phones) availability, which is a customer perk to promote car usage.

It was not found in Beijing, but it does not deny the reference model, which works without Wi-Fi.

5. LESSONS LEARNED AND MAIN CONTRIBUTIONS

As highlighted in Table 8, from the 29 reference model concepts, 5 were not identified in Beijing, and there were 3 concepts identified in Beijing that are not in the reference model.

Regarding the concepts to add to the reference model, the utilization of a mapping process to support vehicle operation seems to be an important support for vehicles operation, and in addition with V2X can avoid road incidents. In Beijing it is referred the existence of V2X, but that cannot be a complete V2X connection, because not all the vehicles are yet connected. The mapping can therefore play an important role while not all the connections are available. Moreover, an app that creates a QR code that ensures customers without sanitary issues is another addressed topic that can be added to the reference model. The existence of one person seated in rear seat, on the other hand, does not seem to be an indispensable concept that should have been raised in the research method, because although that person can bring some confidence, naturally will not exist after the introduction phase. Regarding the Remote Driving Service, that creates confidence to customers, being an important feature to add to the reference model.

About reference model concepts not identified in Beijing, the non-identification of a full physical infrastructure with garage, cleaning and charging place does not mean it can be avoided to exist. Car-pool and carsharing concepts were not identified in Beijing, which do not reject reference model – model works even without those concepts in place, ride-hailing is the service behind the model. Finally, the absence of counterpart in Beijing for the concept's mobility, traffic and Wi-Fi does not also signify a correction to the reference model.

Altogether, to the best of our knowledge, Beijing validates and improves the model. The large majority of reference model concepts were found in Beijing, and the analysis of existing Beijing ride-hailing service, adding the mapping, the QR code to unlock the vehicle and the remote driving capability, boosts reference model.

The most relevant contribution of this research is the presented model, which means that the 120 papers that support the SLR, each one having a specific contribution, clearly show the indispensable stakeholders to support the deployment of SAVs in urban areas. Intuitively, it would not be possible in a different way. It is obvious that autonomous cars operated through a mobility-as-a-service scheme would always need a regulatory framework.

Also, a physical infrastructure (streets, garages, parking, pick-up and drop-off areas) is absolutely essential, as well as the existence of an operator, in order to supply and manage the sharing service, and so on. What is innovative in this research is that by selecting scientific documents and following

scientific procedures (SLR, Topic Modeling) it was possible to obtain the group of stakeholders essential to the deployment of SAVs in urban areas, which can then be used as a "go/ no-go" decision-making tool for policy-makers and investors in their urban mobility strategical options, avoiding false starts and improving "time to market".

6. CONCLUSION

The output of this research is a possible model that systematizes an ecosystem for SAVs in urban areas. The value proposition of this model is its ability to be instantiated to urban areas, presenting the essential conditions for shared autonomous mobility.

Conceptually, the model is the result of scientific documents and processes (SLR, Topic Modeling), which means it is grounded on a solid basis. However, this work has some limitations, starting with the fact that it begins with an SLR which, according to the study [145], presents relevant threats in terms of validity.

As referred, in this research we used different concepts (SLR, Topic Modeling, ArchiMate) in an area that is constantly changing, which means that the achieved result is only a possible model of an ecosystem for SAVs in urban areas, and not the unique or exclusive model.

Besides, this is a predictive model and not a descriptive model, so the reference model is not based on literature that describes a reality, it is based on literature that anticipates a future reality, and reality always brings news, which means that this model will need to be fine-tuned, incorporating findings from real situations.

That was the reason why the authors introduced a comparison with a real situation, in Beijing, where the reference model concepts were confirmed, and 3 other concepts were introduced, reinforcing the model.

Anyway, even with the validation with a real situation that works as an acid test, SLR that grounds this work was limited to articles launched until March 2021, which means that any paper launched after that date can change the model reached in this research.

Finally, while research for this paper was being done, an extraordinary event emerged (the COVID-19 pandemic), imposing changes on all human activities, and autonomous mobility is not an exception.

In fact, according to the study [4], the pandemic seems to have accelerated the development and use of certain forms of vehicle automation for supporting front-line health care (e.g., by delivering medical supplies to hospitals or elderly groups) and controlling the spread of the corona virus (e.g., by disinfecting public spaces), while the discussion about a significant modal shift from airplanes (i.e., short to mid-range trips) to automated vehicles has recently intensified.

At this stage, all these and others possible positive and negative effects are still in an embryonic stage of evaluation, yet without statistical evidences. Therefore, although there are vast news references, there is not yet data dully collected and researched, which provides ground for more future research.

AUTHOR'S CONTRIBUTION

Pedro de Sousa Carneiro, António Reis Pereira and Miguel Mira da Silva contributed to the design and implementation of

the research, to the analysis of the results and to the writing of the manuscript.

CONFLICT OF INTEREST STATEMENT

On behalf of all authors, the corresponding author states that there is no conflict of interest.

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