Shared Autonomous Vehicles Ontology

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Abstract

After rapid technological developments especially over the past decade, autonomous vehicle (i.e., self-driving) technology is expected to be ready for wide deployment soon, with large implications for urban mobility. It is generally accepted that one of the main benefits of self-driving cars could be reduced road congestion, as current roads are expected to have much higher capacity if most of the traffic is shared autonomous vehicles.

On the other hand, the convenience of autonomous vehicles can generate significant further traffic, both from people who currently are not able or prefer not to drive, and more generally, through the concept that increased road and parking capacity often leads to increased traffic. Further gains are expected from using shared autonomous vehicles instead of private ones, with people buying mobility-as-a-service (MaaS), bringing new services to the market such as shared autonomous vehicles (SAVs) instead of just buying cars.

SAV concept is an autonomous rental vehicle flowing from point A to point B that controls all driving functions for an entire trip by itself without any human intervention, such as steering, braking and acceleration, which are performed by a computer system that operates with the support of Artificial Intelligence (AI). The surrounding environment is perceived by sensors, cameras, radars and LiDAR technology. The vehicle navigates to a location/direction through GPS and computer mapping. SAVs enable users to get the benefits of a private vehicle use without the cost of ownership. Once arrived at the destination, travellers do not have to search for a parking lot or pay for it. This paper will focus on the development of a SAVs ontology.

Keywords

Ontology, Shared, Autonomous, Vehicles, Driverless, Self-driving, Robotaxi, Shuttle

Resumo

Após rápidas evoluções tecnológicas, especialmente ao longo da última década, espera-se que a tecnologia de veículos autónomos esteja pronta para uma ampla implantação em breve, com grandes implicações para a mobilidade urbana. É geralmente aceite que um dos principais benefícios dos veículos autónomos poderá ser a redução do congestionamento rodoviário, uma vez que se espera que as estradas atuais tenham uma capacidade muito maior se a maior parte do tráfego for devido à utilização de veículos autónomos partilhados.

Por outro lado, a conveniência dos veículos autónomos pode gerar mais tráfego significativo, tanto de pessoas que atualmente não conseguem ou preferem não conduzir, como, de uma forma mais geral, através do conceito de que o aumento da capacidade rodoviária sem necessidade de estacionamento conduz frequentemente ao aumento do tráfego. Esperam-se novos ganhos com a utilização de veículos autónomos partilhados em vez de privados, com as pessoas a comprarem mobilidade como um serviço (MaaS), trazendo um conjunto de novos serviços para o mercado, como veículos autónomos partilhados (SAV) em vez de apenas comprarem carros.

O conceito SAV é um veículo de aluguer autónomo que flui do ponto A para o ponto B, em que controla todas as funções de condução para uma viagem inteira por si, sem qualquer intervenção humana, como direção, travagem e aceleração, que são realizadas por um sistema informático que funciona com o apoio de Inteligência Artificial (IA). O ambiente circundante é percebido no software do veículo por sensores, câmaras, radares e tecnologia LiDAR. O veículo navega para uma localização/direção através de GPS e mapeamento detalhado da área em computador. Os SAV permitem que os utilizadores obtenham os benefícios de um veículo privado sem o custo de propriedade. Uma vez chegados ao destino, os viajantes não têm que procurar um estacionamento ou pagar por isso, o veículo irá parquear sozinho em locais apropriados foras do centro das cidades. Este trabalho centrar-se-á no desenvolvimento de uma ontologia para veículos autónomos partilhados.

Palavras Chave

Ontologia, Partilhado, Autónomo, Veículo, Sem Condutor, Condução Autónoma, Táxi autónomo, Vaivém autónomo

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List of Acronyms

ADAS	Advanced driver assistance systems
AV	Autonomous vehicle
C-V2X	Celular V2X
CAM	Context aware messages
CASE	Connected Autonomous Shared Electrical (CASE) Vehicle
CAV	Cooperative Connected AV
CV	Connected vehicle
DRS	Dynamic ride sharing
DSRC	Dedicated short range communications
EV	Electrical vehicle
eVMT/eVKT	Empty vehicle miles/kilometers travelled
IoV	Internet of vehicles
LiDAR	Light detection and ranging
LSAV	Local SAV
LTE-V2X	LTE V2X
MaaS	Mobility aaS
ODM	On-demand mobility
PAV	Private AV
SAEV	Shared Autonomous EV
SAV	Shared AV
SEV	Shared EV
U-V2X	Unlicenced V2X
V2B	Vehicle-to-Body (V2B)
V2C	Vehicle-to-Cloud/Edge (V2C)
V2D	Vehicle-to-Device (V2D)
V2G	Vehicle-to-Grid (V2G)

V2H	Vehicle-to-Home (V2H)
V2I	Vehicle-to-Infrastructure (V2I)
V2M	Vehicle-to-Maintenance (V2M)
V2N	Vehicle-to-Network
V2N	Vehicle-to-Network (V2N)
V2O	Vehicle-to-Owner (V2O)
V2P	Vehicle-to-Pedestrian/cyclists (V2P)
V2U	Vehicle-to-Users (V2U)
V2V	Vehicle-to-Vehicle (V2V)
V2X	Vehicle-to-Everything (V2X)
VCC	Vehicular cloud computing
VMT/VKT	Vehicle miles/kms travelled
VTTS	Value of travel time savings

1 Introduction

Autonomous mobility is going to change dramatically our life over the next decade. Shared Autonomous Vehicles won't just change mobility, they could also influence a new way of life in cities. If transportation authorities begin defining the correct policies regarding Shared Autonomous Mobility issues now before autonomous vehicles (AVs) become widespread, they can create a future in which traffic flows smoothly with a reduced fleet, public transportation operates efficiently, and overall emissions drop.

The introduction of SAV in urban areas is nowadays an unavoidable topic, because of its media exposure, because of public carmakers' agendas, leaded by Tesla, and because autonomous mobility is already in a testing phase [53]. The various stakeholders that are taking steps in the direction of autonomous mobility are fueling this testing phase, and the inherent disruption it will create, here considered not as a technological problem, but as a business model change [54], will bring enormous challenges.

Autonomous vehicles can enable the greatest transformation in urban mobility since the automobile invention (named carriage without horses). Full social benefits can only be unlocked if governments understand and implement the appropriate policies and governance frameworks. Cities need to develop a strategy for moving towards an integrated mobility context, where cars are simultaneously autonomous (and connected), electric and shared.

In fact, within cities, at least, a fully autonomous world awaits. Even though this world may be many years down the road, public officials should understand the changes ahead and consider the modifications needed to accommodate such systems. Right now, stoplights and street signs are geared to human drivers. In the future, cities may replace much of this signage with a digital transportation-management system that feeds key information, such as speed limits, sharing restrictions directly to vehicles, without human interaction. In concrete, cities need to develop a strategy for moving towards an integrated mobility platform [55], where cars are simultaneously electric, shared and autonomous. That is, 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) [56], the urban areas where those cars will move will need to be adapted in order to accept this new type of mobility.

The shift that we are witnessing towards vehicle connectivity and autonomy is going to be, perhaps, the most disruptive since the early days of automobiles, and could revolutionize movement of people and goods [57]. Research results in all fields indicate that both short-term and long-term implications of AVs are expected to be significant [58].

The greater use of SAVs will not just change transportation systems, it could also breathe new life into cities. If transportation officials begin looking into Shared Autonomous Mobility issues now before SAVs become widespread, they can create a future in which traffic flows smoothly and predictably, public transportation operates efficiently and overall emissions drop [60]. In addition, SAVs are also expected to reduce accidents, reduce social exclusion and improve the utility of time on traveling [59].

The benefits that such changes could bring to society and to the environment could be beyond price [60]. Just to present a short 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%.

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

An autonomous vehicle is somehow the confluence of referred technological advancements with a vehicle, in practice, it is a vehicle with transportation capacity without interacting with a human driver. AVs can be classified in 6 levels [61 and 62], as summarized below:

- Level 0 - The human driver does all the driving;
- Level 1 - An advanced driver assistance system (ADAS) on the vehicle can sometimes assist the human driver with either steering or braking/accelerating, but not both simultaneously;
- Level 2 - An ADAS on the vehicle can actually control both steering and braking/accelerating simultaneously under some circumstances. The human driver must continue to pay full attention (“monitor the driving environment") at all times and perform the rest of the driving tasks;
- Level 3 - An ADAS on the vehicle can itself perform all aspects of the driving task under some circumstances. In those circumstances, the human driver must be ready to take back control at any time when the ADAS requests the human driver to do so. In all other circumstances, the human driver performs the driving task;
- Level 4 - An ADAS on the vehicle can itself perform all driving tasks and monitor the driving environment. Humans do not need to pay attention in those circumstances;
- Level 5 - An ADAS on the vehicle can do all the driving in all circumstances. The human occupants are just passengers and never need to be involved in driving.

Conversely, AVs will share roads with human drivers for the foreseeable future, and a significant number of collisions due to human driver errors that are simply unavoidable should be expected during this period [63], which means that incoming developments will bring good and bad news, which will be detailed in research questions.

With such context, a Systematic Literature Review (SLR) was conducted to identify the key concepts and relations among them concerning SAVs. The results obtained with the SLR grounded on the development of an ontology, which is a formal representation of the SAVs domain through the definitions and relationships between the concepts of this domain. Ontologies play an important role in the representation of knowledge and reasoning, and, in the field of information systems, are a formal representation of a domain of interest through the definitions and relationships between the concepts of this domain, as a way of achieving a shared understanding [35] and [36]. This study needs to be carried out to identify and formalize, based on an ontology, the key concepts, and main relations between them regarding the shared autonomous vehicles environment.

A Design Science Research methodology (DSR) [52] was adopted to guide the development and evaluation of this ontology and as an artifact to define the terms and relationships between SAVs concepts. Moreover, it was chosen the Ontology Development 101 methodology [2] to support the process of building the ontology. The evaluation was based on instantiating it in an American city context (San Francisco GM Cruise).

The presented document is structured as follows. Section 2 presents the research background, with a more in-depth explanation of autonomous vehicles (AVs) and SAVs concepts as well as enterprise modelling. Section 3 explains the chosen research methodologies (Systematic Literature Review followed by an DSR methodology to guide the development and evaluation of an Ontology using method 101 which is a systematic approach for developing ontologies. Section 4 describes how the SLR was conducted and the phases (planning, conducting, and reporting), motivation of our research, the addressed research questions and the review protocol, the application of the review protocol and the data extraction results. In reporting, are presented the findings from the review and the answers to the research questions. Section 5 presents the seven steps of 101 method for ontology development. In section 6 was described in detail the instantiation phase for ontology evaluation in a real-life situation. Finally, Section 7 concludes the document, including limitations, contributions as well as plans for future work.

2 Research Background

In the following section is found a brief description of autonomous vehicle concepts as well as the possibility of being shared complementing the introduction information. A subsection regarding enterprise modelling is also added with the description of the main method for ontology development.

2.1 Autonomous Vehicles

Autonomous Vehicle can be described as any vehicle that has the capacity to transport people or goods, from point A to point B, without the need of having a human being in control. In the last few years, we have seen a huge development in the technology that supports this concept, such as sensors, cameras, LiDAR, Artificial Intelligence (AI), Machine Learning and Deep Learning, Neuronal Networks, 5G, Big Data and the Cloud.

In terms of automated driving functions, vehicles can be classified into five levels – ranging from driver assistance and partial automation (level 1 and 2), through conditional automation (level 3) and high automation (level 4) to full automation (level 5), in other words potentially driverless. The highest level of automation (levels 4 and 5) can enable new mobility services, such as SAVs.

Shared Autonomous Vehicles (SAVs)

Whilst it is widely acknowledged that automated vehicles (AVs) have the potential to fundamentally disrupt the mobility market, the impacts of the potential utilization of AV have seldom been investigated. According to the framework developed by the Society of Automotive Engineers, fully self-driving vehicles perform all aspects of the driving task, with no human intervention required. As there are no restrictions or limitations, this definition means that fully automated vehicles must be capable of operating under different environmental conditions, providing drivers or, more accurately, passengers the ability to completely turn their attention away from normal driving tasks. Therefore, the convergence of AVs, and the on-demand car-sharing concept i.e., the fleets of SAVs, provides a promising direction for future mobility options [14].

SAVs services will contribute to eliminating the human error that causes vehicle accidents, avoiding sinistrality and its consequent negative effects over the society. AVs can provide massive improvement in terms of time efficiency, reduction in traffic congestion, and better usage of resources. AVs allow people to free up time traditionally spent driving, enabling them to use their time more effectively by working, resting, reading, eating or just doing nothing during the time traditionally spent on driving. Vehicles currently spend over 90% of their time parked [36]. AVs can reposition themselves, away from denser areas, which will enable the development of land previously used for parking places. AVs further enable traffic flow management optimization by the creation of platoons, potentially reducing overall congestion on the roadways/city centres and reducing fuel consumption and CO_2 emissions.

2.2 Enterprise Modelling

Conceptualization is an abstract, simplified view of the world that one may wish to represent for some purpose. It can be represented by the objects, concepts and other entities as well as by the relationships that hold them as a model [36]. Modelling is a proven method for conceptual representation, and in this context, a metamodel, which is a formalized specification of the syntactic nature of the domain under consideration, is core for this activity. Metamodels are explained as a conceptual structure that aims to support the complexity in fast, changing environments [36].

An ontology involves concepts, relationships, definitions, properties, and constraints. It is an explicit specification of a conceptualization. A domain ontology can be a reference ontology that is a special kind of conceptual model, or an operational ontology that is a machine-readable implementation version of the ontology [4]. In this research, it is proposed a reference ontology for SAV domain. In doing so, it aims to share a common understanding of this theme [36].

According to the literature, different surveys [49, 50, 51] on methodologies for the development of ontologies have exposed some common methodologies, namely:

METHONTOLOGY

Methontology is a methodology for ontological development, and is based on the "IEEE standard criteria to design the life-cycle process ontology" [48]. It begins with the "Planning" phase, which consists in defining the reasons to develop the ontology and its uses [48]. After that, is performed the "Specification" phase that states the reason why the ontology is being built, what its intended applications are and who the end-users will be [48]. The third phase is "Knowledge Acquisition", which is characterized by obtaining knowledge drawn from different sources [48]. The following step is "Conceptualization", where the domain of knowledge must be structured to achieve a conceptual model that describes the problem and its solution (relative to the domain vocabulary defined in the "Specification" stage) [48]. Following the "Integration" phase and after that must be executed the "Implementation" of the ontology, which consists in codifying/representing the ontology using a language. Finally, an "Evaluation" must be executed over the ontology [48].

SABiO

SABiO, which stands for Systematic Approach for Building Ontologies [4], is a method for building ontologies, specifically for the development of domain reference ontologies. A domain ontology is built to make the best possible description of the domain. It has been used for building several domain ontologies since its first version was published in 1997 [4]. SABiO allows for the rigorous definition of models, the identification of problems in the definition and interpretation of concepts, and recommendations for model formality improvements [4]. Within domain ontologies, there are two types, reference ontologies (which are a type of conceptual model), and operational ontologies (which are machine-readable implementations of the reference ontology) [4]. There are five main phases in the SABiO development process:

- Purpose identification and requirements elicitation - In this phase, we must identify the ontology's purpose and its intended uses, find its functional and non-functional requirements, and identify competency questions. If necessary, modularize the ontology into a set of sub-ontologies [4];
- Ontology capture and formalization - In this phase, the relevant concepts and relations should be identified and organized. This phase should be guided by the competency questions [4];
- Design - If an operational version of the ontology is to be developed, then it is necessary to implement it in a particular machine-readable ontology language (such as OWL). In this phase, techno- logical non-functional requirements and the ontology implementation environment must be taken into account [4];
- Implementation; Regards implementing the ontology in the chosen operational language [4];
- Test - In this phase, we must verify and validate the behavior of the operational ontology. The testing phase is also guided by the competency questions, and considers mainly black-box testing, although white-box testing may also be considered [4].

101 Method

The 101 method [4], is a methodology of ontology development that consists in the execution of seven steps. It starts by determining the domain and scope of the ontology using, for example, competency questions. After that, step two suggests verifying if it's possible to reuse existing ontologies, usually someone else did it already checking if we can refine and extend existing sources for our domain and task. In step three the important terms in the ontology must be enumerated. The following step (step four) consists in defining the classes and the class hierarchy, using top-down, bottom-up, or mixed approaches. In the next step (5), the properties of each class are defined and in the following step (6) datatype properties are enumerated. The last step (7) is the creation of the instances in a real case situation.

The Ontology Development 101 methodology was proposed in 2001, and since then it has been widely used. According to a Google Scholar search on July 28th, 2022, more than 760,000 papers mentioned this methodology. Since 2018, more than 40,000 research papers were published, and this year, (2022) more than 17,000 articles mentioned it. That's why this was the method chosen to develop this SAV ontology.

3 Research Methods

The methodology chosen for conducting this research is based on an SLR followed by a systematic and more formal approach based on ontology. From the several methods for developing ontologies, we chose the 101 method which is a systematic framework for building ontologies, very well structured and with a validation phase by instantiation.

3.1 Systematic Literature Review

A Systematic Literature Review (SLR) is a way of identifying, evaluating and interpreting all available relevant research information to answer a particular research question, topic area, or phenomenon of interest [1]. It aims to present a fair evaluation of a research topic by using a trustworthy, rigorous, and auditable methodology [1]. This research is based on Kitchenham's guidelines named "Procedures for Performing Systematic Reviews" [1] divided into the following phases:

- **Planning:** clarifies the need to perform a systematic literature review that summarizes all information about a particular topic or domain in an unbiased manner. The research questions, SLR objectives, exclusion and inclusion criteria are defined, and a review protocol must be defined.
- **Conducting:** apply the review protocol previously defined to achieve studies that contain the information that will be the object of the review.
- **Reporting:** This phase intends to write and summarize the extracted information/data from the selected studies, allowing us to get the answers to the proposed research questions.

The three phases of the SLR described above are represented in Fig. 1.

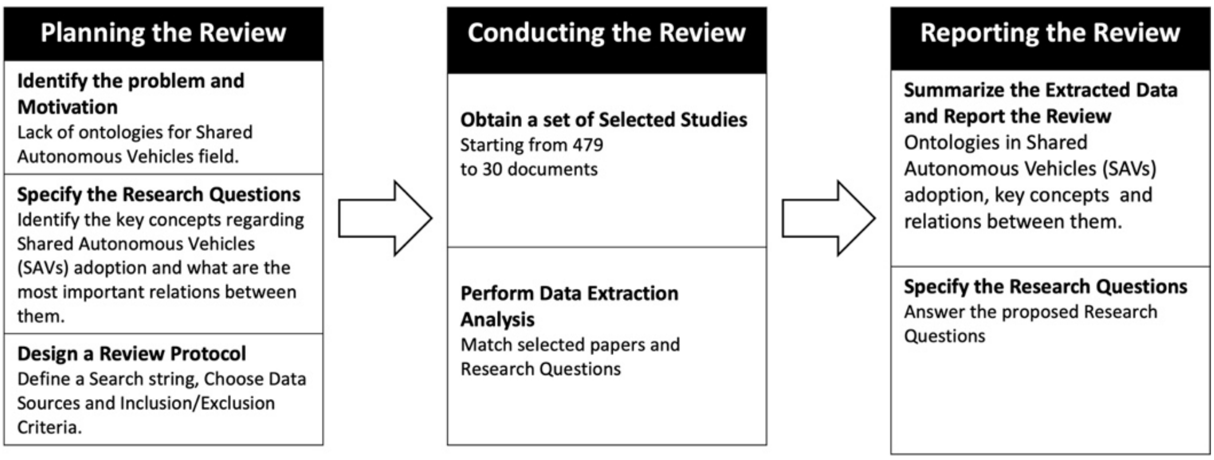


Fig. 1 - The SLR in 3 phases

3.2 Design Science Research Methodology

Design Science Research (DSR) is a methodology in which the research answers relevant questions through the artifact's creation, contributing to new knowledge to the body of scientific evidence. In this environment, the designed artifacts are essential in understanding a real-life problem. This research follows the DSR methodology [52], which encompasses the steps depicted in Fig. 2.

Fig. 2 - DSR Process Model [36]

The "Identify Problem & Motivate" outcomes were presented in the Introduction, as well as the "Define Objectives of a Solution". The artifact developed is a SAVs ontology presented in the following sections.

An ontology by definition [2] is an explicit and formal specification of the concepts in a given domain and the relations between them, such as a formal explicit description of concepts in a domain of knowledge (classes), properties of each concept describing various features and attributes of the concept (slots), and restrictions on those slots (facets). According to [3], it can also be described as an "agreed and shared formal representation of knowledge, a model of formal specification regarding naming and definition of types, properties, and interrelationships of entities that exist in a particular domain of discourse".

Ontologies are useful for domain experts that can use them to share information in their fields of knowledge, as they provide a common vocabulary for researchers, as well to share a common understanding of the structure of information in the given domain [2]. An ontology also enables reuse and further analysis of domain knowledge makes domain assumptions specific and separates domain knowledge from operational [2]. To build a good ontology, it is recommended to follow an ontology-building framework. [4].

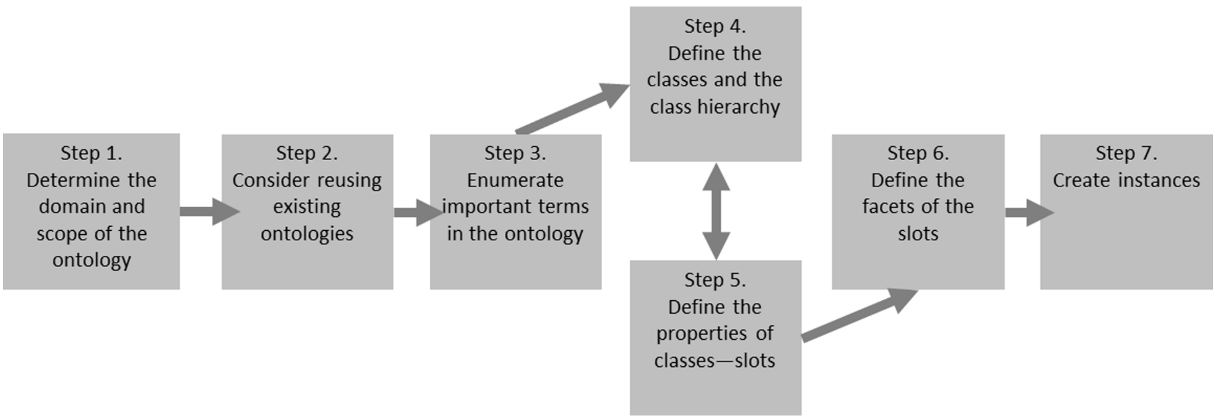


Fig. 3 - The Ontology Development 101 methodology diagram [36]

The methodological approach proposal integrates DSR and Ontology-development methodology, as presented in Fig. 3. First, the researcher has to follow the DSR to identify the problem and show its importance: the "Identify Problem & Motivate" DSR phase (as mentioned before was presented at Introduction section). Next, in the "Define Objectives of a Solution" DSR phase (also presented in the Introduction), the researcher studies which is the better artifact to meet the solution objectives, using the research questions. In the current case, the artifact identified to support solving the problem is an Ontology. Next, the researcher starts the "Design and Development" DSR phase [36]. The researcher uses the Ontology-development methodology approach within this DSR phase. After it is concluded, the ontology definition is the main object to be shown in the DSR Demonstration phase. Then, the other DSR phases follow: "Evaluation of the Artifact's Effectiveness and Efficiency" and "Communication" [36].

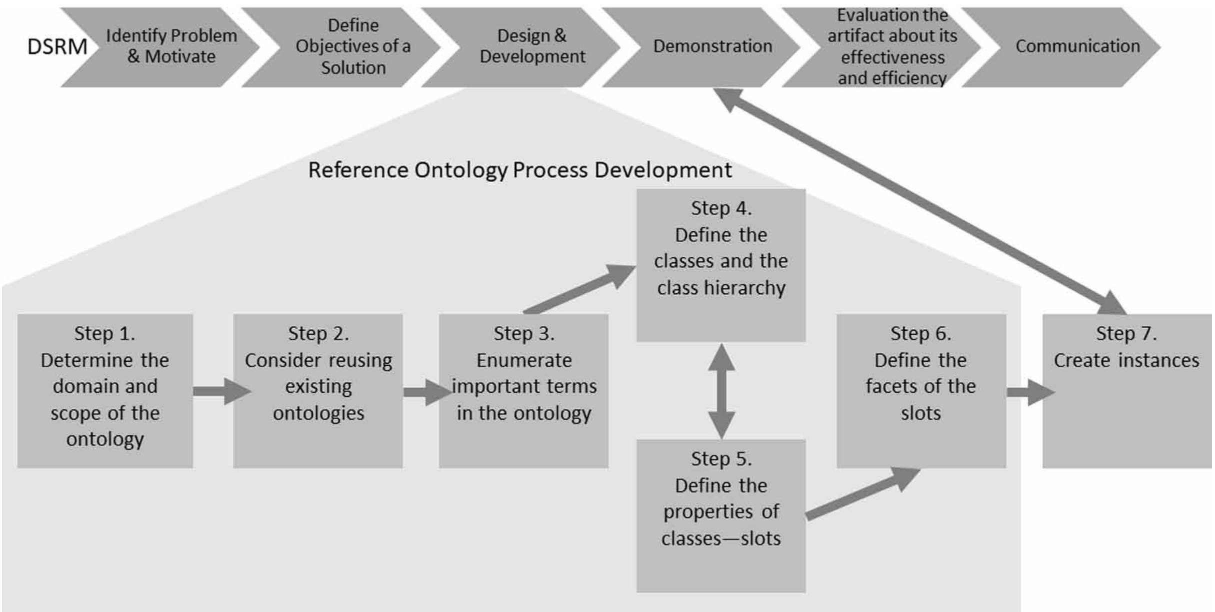


Fig. 4 - Integrated DSR method and the Ontology Development 101 methodology approach for a Reference Ontology development [36]

The methodologies proposed in the literature support the ontological development and aim at the quality of the ontology specification process. Ontologies encode knowledge and make them reusable on various levels. People, databases and applications that need to share information use ontologies [36]. Based on this work, it was set main requirements for the choice of a methodology: be a user-friendly methodology; use a minimum and necessary set of stages and concepts; use clear, unambiguous and well-defined keywords and concepts [2]; Have developmental lifecycle stages clearly identified and described in detail; be interactive, that is, offer the possibility to correct mistakes made in the previous steps; highlight common mistakes and present alternatives for how not to make them.

For this research, Ontology Development 101 approach [4] was chosen, and for the best of our knowledge is a good method for building ontologies, specifically for the development of domain reference ontologies, which is our case. A domain ontology is built to make the best possible description of the domain.

This methodology considers seven steps in the ontology development process, namely:

- Step1: Determine the domain and scope of the ontology
- Step2: Consider reusing existing ontologies
- Step3: Enumerate important terms in the ontology
- Step4: Define the classes and the class hierarchy
- Step5: Define the properties of classes - slots
- Step6: Define the facets of the slots
- Step7: Evaluation - San Francisco GM Cruise SAV implementation

Its iterative process involves a formal explicit description of concepts in a domain of discourse (classes/concepts), properties of each concept describing various features and attributes of that concept (slots/roles or properties), and restrictions on slots (facets/restrictions) [2].

4 Systematic Literature Review

This section presents the execution of a systematic literature review. The presentation follows the three phases (Fig. 2) of the SLR - Planning, Conducting, and Reporting of the results. The world is evolving quickly, and the era of fully automated or autonomous vehicles (AVs) is already a reality today. Waymo, Uber, and others began publicly testing such vehicles in 2017, and Tesla one year before.

4.1 Planning

In this section, the SLR planning is clarified, each research question is specified, data sources are presented and search strategies are defined.

Motivation: AVs may be available for wider public use in many parts of the globe by the year 2035 [25], with many manufacturers, one of which is Tesla, entering the “AV race”. AVs are expected to boost several advantages over conventional vehicles, eliminating the burden of driving. Crash rates are likely to drop due to the absence of human error [28], and these vehicles will operate more smoothly, resulting in emission benefits. On top of this, new services such as SAVs will arise. Developing an ontology on SAVs will allow us to know this reality in an unbiased manner and be a part of this big game and revolution.

Research Questions: The aim of this systematic review goes beyond providing an overview of the current AVs landscape. It intends to search for answers regarding new services that will change urban life dramatically, such as SAVs. This research wants to know what are the main concepts influencing the SAVs domain, as well as the most important relations among those concepts. It also aspires to answer where, why, when and how SAVs are such a game-changer, and what gaps in the literature are still needed to be filled. This research plans to answer the following questions:

- **RQ1:** What are the key concepts regarding Shared Autonomous Vehicles (SAVs)?
- **RQ2:** What are the most important relations among them?

Data Sources and Search Strategy: During planning, the need for an SLR was identified, and the research questions were defined. In Conducting phase it was used EBSCO as a reliable source that can supply relevant and important information from main scientific databases, a complete search string with main terms in the SAVs domain, and a search strategy using as sources only peer-reviewed papers from academic journals or conferences.

4.2 Conducting

The second phase of the SLR consists of conducting the review, where the selection of studies and publications are chosen in the literature according to a given inclusion and exclusion criteria. In the case of this research, the selection of literature was made based on the search criteria describes in Table. 1, and resulted in a total amount of 339 papers.

Table 1 - Data source, search string and strategy

Element	Research Details
Source	EBSCO
Final Search String	Shared AND (“Model” OR “Metamodel” OR “Ontology” OR “Taxonomy” OR “Framework”) AND ("Autonomous" OR "Driverless" OR "Self-driving") AND ("Vehicle" OR "Car" OR "Auto" OR "Automobile" OR “Taxi” OR “Robo-Taxi” OR “Robotaxi” OR “Shuttle” OR “Cab” OR “Cav”)
Search Strategy	Articles in academic journals or conference materials, with full text available, peer-reviewed, in English and without a date range limit.
Total	**339**

Once the final papers for full analysis were selected, data extraction, monitoring, synthesis, and interpretation took place. To obtain the final set of papers, a process with several filtering stages was executed over the first set of 479 papers collected (Fig 2). After filtering per full-text availability and peer-reviewed, a set of 341 papers remained. After that, we’ve filtered by academic journals or conferences and English language only, 339 papers remained, and after removing duplicates we got 196 papers (Fig. 5).

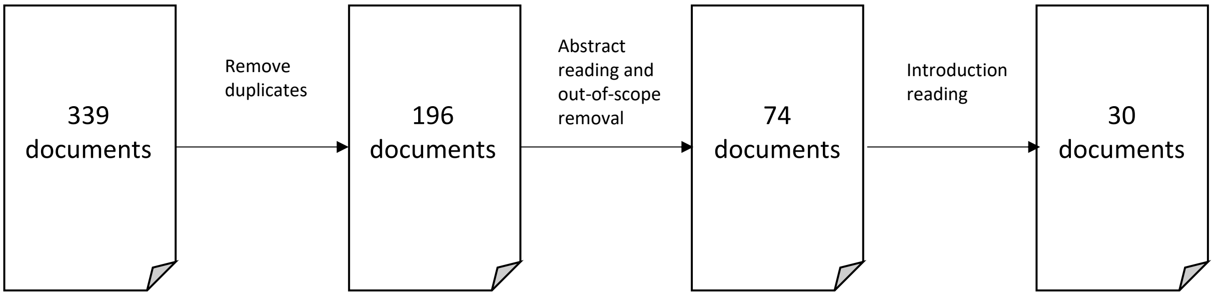


Fig. 5 - Papers, Conferences, Publications Filtering process

Inclusion and Exclusion Criteria: The titles and abstracts of these papers were read and classified into two types:” accepted” and” rejected”. In total, 122 papers were excluded because they were out-of-scope. Abstracts, introductions, and conclusions of the remaining accepted 74 papers were fully read and resulted in the further removal of 44 papers due to a lack of information to respond to defined research questions. In the end, a final set of 28 papers from different academic journals and 2 from conferences (Tables 2 and 3) were obtained. It is important to refer that reached articles are quite recent which means this is an actual topic being researched by a growing number of people (Fig.6).

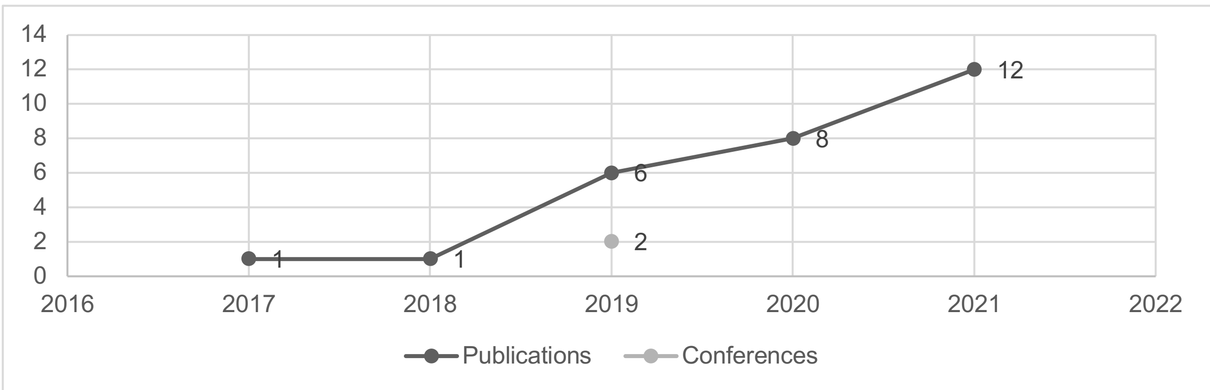


Fig. 6 - Publishing year of selected SLR papers

Table 2 - Conferences

Conference	Number of Publications
IEEE International Conference on Network Protocols (ICNP)	1
IEEE Intelligent Transportation Systems Conference (ITSC)	1
Total	**2**

Table 3 - Academic Journals and Publications

Journal, Publication	Number of Publications
Transportation Research Part C: Emerging Technologies	6
Transportation Research Part A: Policy and Practice	4
Transport Policy	2
Sustainability (Switzerland)	2
Journal of Cleaner Production	2
IEEE Transactions on Intelligent Transportation Systems	1
Journal of Advanced Transportation	1
Journal of Transport and Land Use	1
Personal and Ubiquitous Computing	1
Research in Transportation Business and Management	1
Research in Transportation Economics	1
Robotics and Autonomous Systems	1
Technological Forecasting and Social Change	1
Transport Reviews	1
Transportation	1
Transportation Research Interdisciplinary Perspectives	1
Vehicles	1
Total	**28**

4.3 Reporting

In this section, the results from the analysis and interpretation of each selected paper and key collected information are presented, allowing us to answer the best way to defined research questions.

4.3.1 Key concepts regarding Shared Autonomous Vehicles (SAVs):

From the detailed analysis of selected papers, main concepts regarding SAVs were identified and presented in Table. 4, produced by authors and organized by decreasing number of sources. Then, it is presented a discussion evolving these main topics, including favorable and unfavourable arguments regarding SAV concepts adoption.

Automated vehicles are vehicles with some level of automation to assist or replace human control [5]. The Society of Automotive Engineers (SAE) has defined different levels of automated functionality, ranging from no automated features (Level 0 - the driver controls the entire process manually without any system assistance) to full automation (Level 5 - the system acts alone without any interaction with the driver, absence of a steering wheel), usually referred as autonomous, self–driving or driverless vehicles). In between there are Level 1- the system can assist the manual control if the driver activates it; Level 2 - the system partially takes over some control tasks but the driver has to be ready to intervene and can take back control at any time; Level 3 - the system can make decisions alone but the driver has to remain capable of taking back control if the system fails. Level 4 - the system can make decisions alone and intervene if something goes wrong, but the driver still has the possibility of returning to manual control [5].

Table 4 - Key concepts regarding SAVs adoption

Concepts	Sources
Autonomous Vehicles (AV) - possibility to be shared	[5,6,7,8,9,11,12,13,14,18,21,24,25,27,29,30,31]
SAVs - shared autonomous vehicles, (CAVs) - connected autonomous vehicles	[5,6,7,8,9,12,13,14,16,17,19,21,22,24,28,30]
Ridesharing - carsharing, ridepooling	[7,12,14,15,22,23,28,30]
Demand - induced, increment of trip demand	[5,12,14,15,19,22,28]
Safety increase - eliminating human error	[6,11,20,21,25,26]
Driverless - Robotaxi, Shuttle, Self-driving, Level 5, Full Automation	[5,6,10,11,22,26]
Ownership - reduction due to SAVs	[9,17,23,25,31]
Policy	[11,15,16,21,28]
Green - fleet and traffic optimization reducing emissions	[6,7,8,26,28]
Congestion reduction and pricing	[6,8,13,19,28]
Deployment method	[5,9,20,26,30]
Urban optimization - new areas where before parking	[5,6,8,9,19]
Connected Vehicles (CVs)	[19,21,26,32]
Urban sprawl - AV repositioning from city centers	[6,9,10,19]
Fleet - reduction	[5,15,25,28]
Efficency increase - using resources	[6,11,21]
Individual characteristics - opinion towards AVs	[6,14,33]
Traffic - increase/assignment, extract route flows and travel time	[5,10,13]
Acceptance - SAVs services	[12,23,31]
Pricing - schemes	[5,8,13]
LSAVs - local SAVs	[20,31]
Promoting - AV usage	[6,12]
Usage - choice decision	[6,13]
Charging - electrical vehicles EVs, SAEVs, monitoring battery, charging strategies	[5,26]
Mobility-aaS	[25,33]
Parking - area reduced and away from city centers	[5,6]
Vehicle - assignment to the customers	[5]
Redistribution - vehicle	[5]
Endowment Effect	[9]

Some aspects were considered significant in AV potential usage and choice decision: enjoying driving, environmental concern and Pro-AV attitude [6]. The effects of the attitudinal variables are very significant and can be influenced through educational campaigns to change future choice decisions. Also, it was found that men are more likely to adopt self-driving cars than women [6]. This inclination of men towards AVs is confirmed because men purchase AVs earlier, have fewer concerns with AVs and think they are safer. It was also found that men would be willing to pay more for automation than women, in addition to being less worried about full automation [6].

The main components of SAV modelling are the following: (a) Demand, (b) Fleet, (c) Traffic Assignment, (d) Vehicle Assignment, (e) Vehicle Redistribution, (f) Pricing, (g) Charging and (h) Parking. The component Demand involves the estimation of demand in the implementation area and mode share for SAV services. With regards to the Fleet, studies mainly aim at estimating the required fleet size to serve a given demand and fixing the initial position of the vehicles. The Traffic Assignment component is used to extract route flows and travel time between origin and destination nodes. The vehicle Assignment component assigns vehicles to the customers, which can be based on certain rules, heuristics, or an optimization algorithm. The component Pricing includes the estimation of fare of SAV trips based on spatial (customer origin and destination) and temporal parameters (demand levels at a different time of the day or based on network congestion). Charging refers to monitoring the battery levels of electric vehicles and strategies to charge vehicles. Finally, the component of Parking involves estimating parking requirements and includes the strategies to park vehicles [5].

While maintaining the same service level, ride-sharing - combining autonomous driving with mobility-as-a-service (MaaS) - can potentially decrease the fleet size by up to 59% without significant waiting time increase or additional travel distance; the benefit of ridesharing/ridehailing/ridepooling (defined in Table. 5) is significant with increased occupancy rate (from 1.2 to 3), decreased total travel distance (up to 55%) due to fleet decrease, and reduced carbon emissions (725 metric tons per day) [7].

Since driverless passenger vehicles represent a new travel option, many passenger trips made via existing, traditional modes, like cars, public transport and bikes, will be replaced by trips made using AVs and SAVs. While AV and SAV benefits may accrue in improved accessibility, road safety and energy consumption, network congestion impacts are less well understood and may be quite problematic. On one hand, automated technologies can ultimately improve network performance by reducing traffic crashes (and the delays they entail) and eventually increasing traffic by ensuring tighter headways between vehicles and by making better use of intersections. However, AVs and SAVs will likely increase the number and the distance of motorized trips by eliminating the burden of driving and by making car travel more accessible (to persons with disabilities and those not owning cars, for example). Congestion may dramatically worsen, and demand management options will become even more valuable along congested corridors and in urban regions. All the investigated congestion pricing (CP) significantly show a trend in the decrease of traffic demand and reduce delays. Presumably, they will also reduce emissions, collisions, noise, and infrastructure damage [8].

Regarding prospects and challenges for AV and their method of deployment, we distinguish three basic structures for the implementation of AV Private ownership of vehicles by individual households - this would be like the current structure of private ownership of automobile [9].

Private ownership of fleets of vehicles by operators -this would be like the Uber and Lyft paradigm. Public ownership of fleets of vehicles by government agencies - this would be like the current system of public transit, with features of demand-response [9].

Each of these systems of deployment has the potential to impact transportation and urban form in varying degrees. There is currently no consensus in the literature as to the most probable system of deployment. This research suggests private ownership of AV would not be attractive in a future of sophisticated 24/7 mobility-on-demand, but subsequent cost-benefit analysis finds private ownership (Fleet operators) to be the cheaper alternative [9]. A theoretical complication with a potential transition away from private ownership of the vehicle is termed the Endowment Effect, which finds that people sometimes value ownership of a commodity more than market willingness to pay for it. In the case of AV, this means a shift to shared vehicles may require a utility benefit greater than expected based solely on the characteristics of the alternative modes [9].

Regarding land-use effects, most studies expect AV to produce increased urban sprawl. This is premised on decreased headways and more efficient driving by computers leading to higher capacities on existing roads. The prevailing wisdom is that the associated decrease in travel disutility will cause people to travel more frequently and across greater distances [9]. Self-driving cars would allow parking farther away from the origin or destination of a trip. We have seen that this would further reduce the number of parking spaces required. This benefit, nevertheless, comes at a price of increased traffic, which we quantify here as an increase in the total vehicle miles travelled (VMT) [10].

It is expected that autonomous driving may significantly change travel behavior and mode choice, potentially transforming our understanding of mobility in a way that it is hard to predict at this point. At the same time, understanding user preferences, once autonomous driving is available, becomes increasingly relevant in light of urbanization trends, demographic change and environmental challenges. Even though vehicles with level 5 automation will potentially enter the market no sooner than 2027 [11], and it might take decades for the technology to reach a substantial penetration rate, anticipating its future impact on mobility is crucial for developing a desirable transition pathway of the technology. Along these lines, offering early insights into the potential impact of automation on user preferences is of great importance for policy and transport planning authorities. Those insights are crucial to design strategies and in evaluating future possible scenarios, to integrate AVs into transport systems in a way that allows for their full potential to unfold, while preventing, or at least mitigating, potential negative developments [11].

Moreover, it is well-known that fully autonomous operations will not happen all at once, but it is expected to occur over some period through an incremental process [12]. As such, it is important to first explore the public acceptance of the AV modes in relation to the conventional mode available during the transition phase. Any measures from governments, such as promoting the use of any AV-oriented ride-hailing or ridesharing service or restricting the use of private cars or banning them from certain areas could be unpopular. While the stride and scale of AV market development will be established by consumer demand, the anticipated societal benefits cannot be reached until a critical mass of consumers accepts and uses this technology [12].

Considering mobility as the “normal good”, lower travel costs are expected to increase total vehicle kilometers, i.e., the number of conventional (driver controlled) private car (CC) and SAV trips and/or the CC and SAV trip distances. The expected increase in traffic may result in inefficient usage of resources and a loss in system welfare. Pricing policies should therefore be implemented to develop integrated pricing schemes for all modes of transportation, in particular, the CC and the SAV mode [13]. A fare above operating costs or a minimum fee will decrease the number of transport users switching from bicycle and walk to the SAV mode, which may be the desired effect. However, without an increase in costs for CC users, a higher SAV fare also pushes users from the SAV to the CC mode. For CC users, introducing or increasing parking costs may have a similar effect as tolling. Furthermore, to tackle the increase in traffic volume on minor roads in residential areas, SAV operators or regulators should re-think door-2-door service, and instead possibly define virtual pick-up points that are located conveniently for users and well accessible for SAV operators. We can see this concept in Beijing Olympic Park, where Baidu Apollo has it in place [13].

The advent of AVs could stimulate the adoption of car-sharing, as it is being defended by Elon Musk concerning AV to return to the shared platform when vehicles are not needed (www.tesla.com). Nevertheless, public opinion on AV technology can be partially applied to SAVs. Given that AVs allow drivers to turn their attention away from driving tasks completely, it could be of particular interest to individuals who have no access to private travel modes or who may be unable to drive, such as the elderly, disabled, children and others [14].

Several factors are contributing to the measured empty VMT, with demand profile, fleet size and fleet operation policy among the most important ones. Another important factor contributing to the measured empty VMT is the customer model. Many studies model customers, who wait for an infinite amount of time (in theory) until they are served, without considering that the customer might not accept such a service. Customer impatience was modelled by allowing customers to walk away from the system if they do not receive service in 6 minutes, a value supported by the ride-sourcing service Uber [15]. A possible solution to increase the occupancy and decrease the number of vehicles on the streets and consequently also VMT, while still offering a flexible door-to-door service, could be sharing trips or part of the trips between multiple On-Demand Mobility (ODM) users at the same time, which we denote as on-demand ride-pooling. Pooling multiple customers into one vehicle at a time is one way to improve the amount of person throughput of the existing street infrastructure. Ride-pooling systems might contribute to an improvement of traffic conditions and therefore pollution reduction [15].

The consequence of this ethical dilemma is a social dilemma that involves public acceptability of this new technology that probably causes a sort of a priori reluctance towards autonomous vehicles because of their implications for perceptions of both personal safety and security (e.g., hackers taking control of self-driven cars). This reluctance to change could mean a sort of lack of trust (unwillingness to pay) regarding this new technology. Public acceptability of self-driving mobility is a topic that only recently has gained the interest of researchers including the topic of SAVs and their acceptability issues. This is because, although the main interest of manufacturers and policymakers in autonomous vehicles is their diffusion in the private car market, it is probably in the public transport sector that this technology will be used first [16].

From studies on the impacts of the SAVs on vehicle ownership from the perspective of consumers, it is argued that the advent of SAVs has the potential to reduce the level of car ownership, stating that SAVs could reduce up to 43% of vehicle ownership. However, the full benefits could only be achieved if consumers are willing to give up their private vehicles for SAVs [17].

Vehicle automation should in principle change the supply in several ways. The most significant would be a reduction in inter-vehicle headways, by removing the time required for the driver to react to the vehicle in front [18]. This in turn should increase the capacity of the existing road network. However, the full effect would only be realized with full automation. The second impact would be through a reduction in accidents and near misses, which arise largely through human error [9]. These have a more unpredictable impact on capacity, but their reduction should substantially reduce the variability of travel times in a network. The third impact would be on speed, which would depend on vehicle capabilities and system settings. The final impacts relate to parking. At present, a significant proportion of peak traffic is due to searching for parking spaces, and an automated vehicle should be able to identify an available parking space and travel straight to it. As an extension, it would no longer be necessary for the vehicle to remain parked at its user's destination. Shared vehicles would simply move on, empty, to collect their next user; privately owned vehicles could return empty to locations where parking is free. In both ways, the need for parking in city centres should be reduced. The study was developed at the International Transport Forum, using a simulation framework previously developed at the University of Lisbon to explore ride-hailing business models for the city of Lisbon, and concluded that surface parking would be no more necessary. With on-street parking largely removed, thus further increasing road network capacity, some off-street provisions would become available for conversion to other uses [18].

Moreover, indirect effects will change the demand behavior. Indirect effects of AVs will cause changes in the system equilibrium between transport supply and demand. As a result, new requirements for infrastructure will be necessary for the long term:

- Reduction in the subjective value of travel time savings: Users of AVs will do other tasks instead of driving, reducing the disutility of the travel time [19];
- New users to the vehicle system: AVs will expand the range of users that will use these cars (e.g., minors, the elderly and disabled people) [19];
- Induced demand: The reduction of the value of time, congestion, and travel times will cause the increment of trip demand in AVs and SAVs. The changes in travel patterns will impact the reduction of transit users, and AV and SAVs could increase. Therefore, this phenomenon will encourage the vicious circle of public transportation [19];
- The increment of vehicle kilometers travelled (VKT): The increment of the VKT has at least three reasons. First, splitting of joint trips in which two or more members of a family that are currently travelling together could travel separately with AVs. Second, AVs will move without passengers ("ghost trips"). Moreover, transportation costs will be lower due to a better amortization of a vehicle [19];
- Changes in trip distribution: The improvements due to direct effects, such as the reduction of congestion, costs and the value of travel time, will cause longer trips [19];
- Changes in the place of residence, work, or both, will imply changes in the generation and attraction of trips [19];
- Changes in the urban structure and urban activity system: Changes in trip distribution will imply an increment in the city size in the long term. The urban model will change to a dispersal model (urban sprawl) because new urban areas will be built in places far away from the city center [19].

Social equity was an important issue for workshop participants, with local SAVs (LSAVSs), which are SAVs operating in a small area such as a campus, seen to provide mobility for those who experience shortfalls in mobility or lack of access to transport currently; circumstances identified as arising from patterns of provision of services, their cost or social and cultural factors. To achieve social equity benefits, services would though need to be secure from crime and antisocial behavior, safe to use as a transport service and affordable. These attributes would be particularly important for vulnerable traveler groups [20].

Safety, security and the need for trust in AVs are very important. The new technology needs to be proven safe and robust against hacking, for example. It must also be safe for other road users and pedestrians.

Security from potential threats due to illegal or antisocial behavior by others was also important, with explicit monitoring in the vehicle expected and wanted. Participants in the study expected LSAVSs to follow a dynamic ride-sharing (DRS) model of sharing, albeit there were some concerns around vulnerable users and vehicle monitoring for safety. The possibility of women-only vehicles was raised, or extensive monitoring through mechanisms such as CCTV or live links to control centres. The ‘defence’ of personal space within vehicles also emerged as important, with calls for LSAVs to be configured in such a way as to give clear indications about personal space allocations, so avoiding unwanted encroachment by others into the personal domain [20].

AV technologies have inherent shortcomings. The limitations of AV sensing technologies are highlighted by the well-known fatal accidents of Tesla cars with autopilot in 2016 and Uber self-driving car in 2018. Questions arise concerning reliability under extreme weather or road conditions. The artificial intelligence (AI) models used for AVs are mainly operated in blackbox mode (a complex system or device whose internal workings are hidden or not readily understood), meaning that the AI algorithm is used without clear explanation and transparency. On the other hand, connected vehicles (CV) technology is fully dependent on a message exchange to build mutual awareness, which can only have a noticeable impact when there is a high CV penetration [21].

Technically, there are still key challenges around the existing CV, AV technologies as well as on the emerging cooperative connected autonomous vehicles (CAV) technology. Non-technically, one major challenge for cooperative CAV is that there is a lack of interest in cooperation from the key players, such as car makers, CV telecommunication companies and policymakers. Carmakers usually prefer to have full control of their AVs and close system with advanced sensors and self-driving algorithms. Apart from the potential security attacks, there is a legal concern on the responsibility for potential accidents due to the use of inaccurate sensing information shared from other vehicles [21].

Fully self-driving vehicles, once they become available, will impact these options and others. They can be adopted with or without a human driving option and can be owned privately or shared by multiple users. If self-driving vehicles are shared, they can be dynamically shared among the users by matching them in real-time. DRS has become possible with smartphone applications and network technologies, while non-DRS represents traditional matching of users for car-pooling. When SAVs are empowered by DRS concepts, they can increase demand for motorized-vehicle trips and even undercut demand for public transit, bikes, and non-motorized modes. Among various changes expected in the future, this research is focused on the evolution of powertrain and the adoption of autonomous vehicles. Among powertrains, the market share of electric vehicles (EVs) may increase because of their environmentally friendly features and lower energy cost [22], which means a future combination trend of vehicles that at the same time are autonomous, shared and naturally connected, using clean energy.

Another strand of research, more frequent in the literature, investigates user acceptance and preferences of owned and shared automated vehicles, sometimes along with other options (mostly manually driven owned vehicles). While a willingness to pay for ownership or convenience of automated vehicles cannot be established through these studies, they tend to indicate a strong aversion to sharing a ride with unknown passengers in the automated vehicle [23].

At the same time, there is an aspiration, and sometimes an expectation, that AVs would contribute to a shift towards shared mobility services using shared autonomous vehicles (SAV), for example, within the Mobility-as-a-Service (MaaS) context. Studies conducted from Lisbon to Singapore, have demonstrated that SAVs can reduce the urban fleet required within a city up to 90% if such vehicles are shared, although with only marginally lower VMT (Vehicle Miles Travelled) or with even increased VMT, since this would depend on the adoption of shared AVs by users. We can see this in the car-sharing study that was developed at the International Transport Forum regarding Lisbon [24].

Concerning the impact of AVs on travel, AVs could increase the accessibility of travelers (especially to those who cannot drive) and reduce barriers in trip making as the vehicle will have more usability. Considering a lower burden of travel, AVs may reduce the burden for longer distance travel and encourage the users to move away from the cities, which results in urban sprawl. The reliability of AVs may avoid contingency planning on the part of individuals to reach a specific time at their desired destination as people may be aware of their exact travel time due to high connectivity and efficient optimization of the network. The initial cost of owning AVs can be high; however, it could decrease with more market penetration. Another attribute that is related to cost, the auto insurance cost, will be reduced. As in the case of incidents, liability may be shifted from users to manufacturers of AVs (as the human error will not be involved instead of an incident that may happen because of technical failure [25].

Car sharing platforms can provide faster application scenarios for emerging technologies such as electric, autonomous or driverless vehicles, which has led to the emergence of SAEV (shared, autonomous, electric vehicles) technologies, where each of which has its advantages and challenges. Electric vehicles reduce the emissions from existing petrol-powered vehicles, autonomous vehicles improve safety and shared mobility provides a more direct way to shape the future and provides affordable, accessible and fair multimodal transport options. This integration of technologies makes SAEV innovations not only economically viable but also economically attractive [26].

Many studies on the future impact of AVs have been conducted, focusing on microscopic and macroscopic network analysis and simulations. Their results show that AVs allow shorter headways between the vehicles, increasing the freeway network's capacity by 30% and reducing traffic delays significantly for higher penetrations rates of AVs. In contrast, low penetrations did not yield noticeable capacity benefits [27].

If SAVs are preferred in the future, travel demand modelers must study the impact SAVs may have on the system to understand and mitigate negative externalities (like congestion, emissions and inequity) with effective policies. In the recent past, a huge number of studies on single-occupant SAV operation under varying regional settings have warned regions that congestion will worsen through added vehicle-miles travelled (VMT), especially from the non-revenue generating unoccupied miles (empty or eVMT) necessary to pick up travelers. Fleet operational policy, such as allowing multiple travelers to share their rides, and DRS, are anticipated to moderate rising congestion from SAV fleets and, in some cases, even lower congestion by reducing total VMT if large demand for SAVs exists [28].

The main research challenges to apply such shared control models based on levels of autonomy are (1) finding the best compromise of shared control between humans and autonomous systems, (2) the transition between levels of autonomy, and (3) the possible conflicting decisions between humans and autonomous systems [29].

Individuals interested in new technology were more willing to adopt SAVs for schooling and working trips than other trips in both cities. This suggests that the “automation” of vehicles would be more effective during peak hours of work and schooling. This finding is in line with the previous study that early adopters showed more interest in new technology. This study considers SAVs without pooled options, which provide the same level of privacy as a private car. On the contrary, SAVs with pooled options imply the sharing of a vehicle with strangers, which is a downside for many passengers [30].

The connected vehicles interact with the surrounding environment and infrastructure using two-way intelligent cellular/wireless connectivity capabilities to exchange real-time data to other vehicles, mobility solutions stakeholders, the edge/cloud computing infrastructure, and provide over-the-air function updates and upgrades. Advanced vehicle connectivity represents a critical element supporting the mobility sector’s digitalization and implementing shared economy services and applications [31].

These open-to-innovation and technology-embracing attitudes among Millennials presented them as early adopters and stable customers of shared mobility services. Ridesourcing services (such as Uber and Lyft), which use online platforms to connect travelers and drivers via an automated reservation and checkout system, are the most popular forms of shared mobility services. The literature showed that young people were more likely to adopt ride-sourcing services and showed a considerably higher frequency of ride-sourcing usage than older adults [32] [33].

4.3.2 What are the most important relations among them?

SAV services can be divided into on-demand (the customers can book vehicles in real-time), reservation-based (booked in advance) and mixed systems. The current state of operation of shared vehicles, i.e., current request scenarios for shared vehicle services are primarily on-demand. However, reservation-based systems enable better planning of routes and schedules and, if optimally designed, higher efficiency, thereby reducing fleet size, empty cruising time and operating cost, as well as increasing resource utilization [5].

With regards to pricing structure, SAV services can be differentiated as services with fixed or dynamic pricing structures. As the name implies, fixed pricing structure involves charging customers based on mileage or travel time and, in the latter case, origin-destination based and time-of-day based pricing. Based on vehicle ownership and network operations, the study mentions six potential business models: (i) Business–to–Consumer (B2C) with single owner-operator, (ii) B2C with different entities owning and operating, (iii) Peer–to–Peer (P2P) with third–party operator, (iv) P2P with decentralized operations, v) Hybrid ownership with the same entity operating and (vi) Hybrid ownership with third–party operator. Vehicle equipment and entertainment systems (including Wi-Fi) are not important. Most of the users are unwilling to pay extra charges for individualization (ridesharing to carsharing). Also concludes that users have different expectations for autonomous vehicle user interface, based on whether the vehicle is owned or shared [5].

Costs are an important variable in the choice to use SAVs, though 25% of individuals would refuse to use SAVs even if completely free. The price of AVs is not important, what is more important, is the relative price between AVs and regular vehicles. It is also pointed out the increase the concern that individuals have for the environment, carsharing and public transit systems. Individuals who currently have low opinions of transit systems and who never use public transit are less likely to choose SAVs. Individuals with longer commutes (in terms of both time and distance) tend to have a greater appreciation of the benefits of AVs. This is an early indication that autonomous vehicles may enable individuals to commute longer distances, thereby increasing urban sprawl and vehicle miles travelled. Given this early indication, pre-emptive measures should be undertaken to prevent negative impacts of AVs on land use and travel patterns [6].

From the detailed analysis of selected papers, relations between the main concepts regarding SAVs adoption were identified and are presented in Table 5 and Fig. 7, both produced by authors and organized by decreasing number of sources.

Table 5 - Relations between key concepts regarding SAVs adoption

Concept A	Relations Between Concepts	Concept B	Sources
SAVs	User Willing-to-Pay (WTP) higher in AVs with human-driven option, causing SAVs usage dilemma	AV with human driven option	[5,9,14,16,17,22,23,30,33]
SAVs (CVs;CAVs;MaaS)	Commute longer distances	Mobility enabler	[6,12,14,17,18,19,21,30]
SAV/AV	AV/electrical vehicles (EV) shared mobility implies fleet reduction	Efficiency	[5,7,9,14,15,21,22,28]
Efficiency	Fleet and traffic optimization reducing emissions (Going Green)	Low emissions	[6,7,8,22,23,26,27,28]
Efficiency	Efficiency regulates pricing, congestion reduction due to pricing increase along with traffic (tolling)	Pricing	[5,8,19,22,23,28,34]
SAV shared ownership	Ownership (private vs shared), will lead to different deployment methods and business models	AV private ownership	[5,17,18,25,30,32]
Ridesharing shared	Dynamic ridesharing/carsharing increase due to the unwilling to pay for individualization	Carsharing individualized	[5,7,30,32,33]
Deployment methods	Deployment methods will influence policies	Policies to be in place	[5,9,20,26,30]
SAVs repositioning	SAVs repositioning from city centres cause urban sprawl (longer commutes)	Urban sprawl/longer commutes	[6,9,10,12,18]
SAVs tech, law and ethics	Trust in new Technologies will increase with legislative and ethical clarification in the way for full adoption trust	Trust for full adoption	[12,16,20,33]
SAVs more trip-making	More trip-making demand is induced due to reduced parking demand	Parking demand reduced	[7,10,19,32]
Safety	Trust for full adoption is hindered by safety concerns	Trust for full adoption	[5,20,21,22]
Driverless	Driverless (Robotaxi, Shuttle, Self-driving, Level 5, Full Automation) will increase efficiency	Efficiency	[5,8,16,34]
Ridesharing with strangers	Individual characteristics regarding aversion to sharing rides with strangers will slow full adoption trust	Trust for full adoption	[23,25,33]
Parking demand reduced	Parking reduction will lead to urban development in old parking areas, and more efficient land/energy consumption	Efficiency	[9,10,19]
SAV acceptance	Understanding users willingness for SAV services needs to cross psychological barriers in order to increase trust	Trust for full adoption	[14,16,20]
SAV service cost	AV vs regular vehicle relative price will be influenced by WTP individual characteristics	AV private ownership cost	[6,13,23]
Traffic reduced and optimized	More efficient traffic assignment extracting route flows and optimized travel time	Efficiency	[7,13]
SAV	Local SAVs (LSAVS) services will require social acceptance	Local service	[20,31]
SAEV	Shared autonomous electrical vehicles (SAEVs) charging strategies/battery monitoring optimization will increase efficiency	Efficiency	[26]
AV private ownership	AV private ownership increases due to the fact that user values ownership more than WTP (Endowment Effect)	Willing to pay (WTP)	[9]

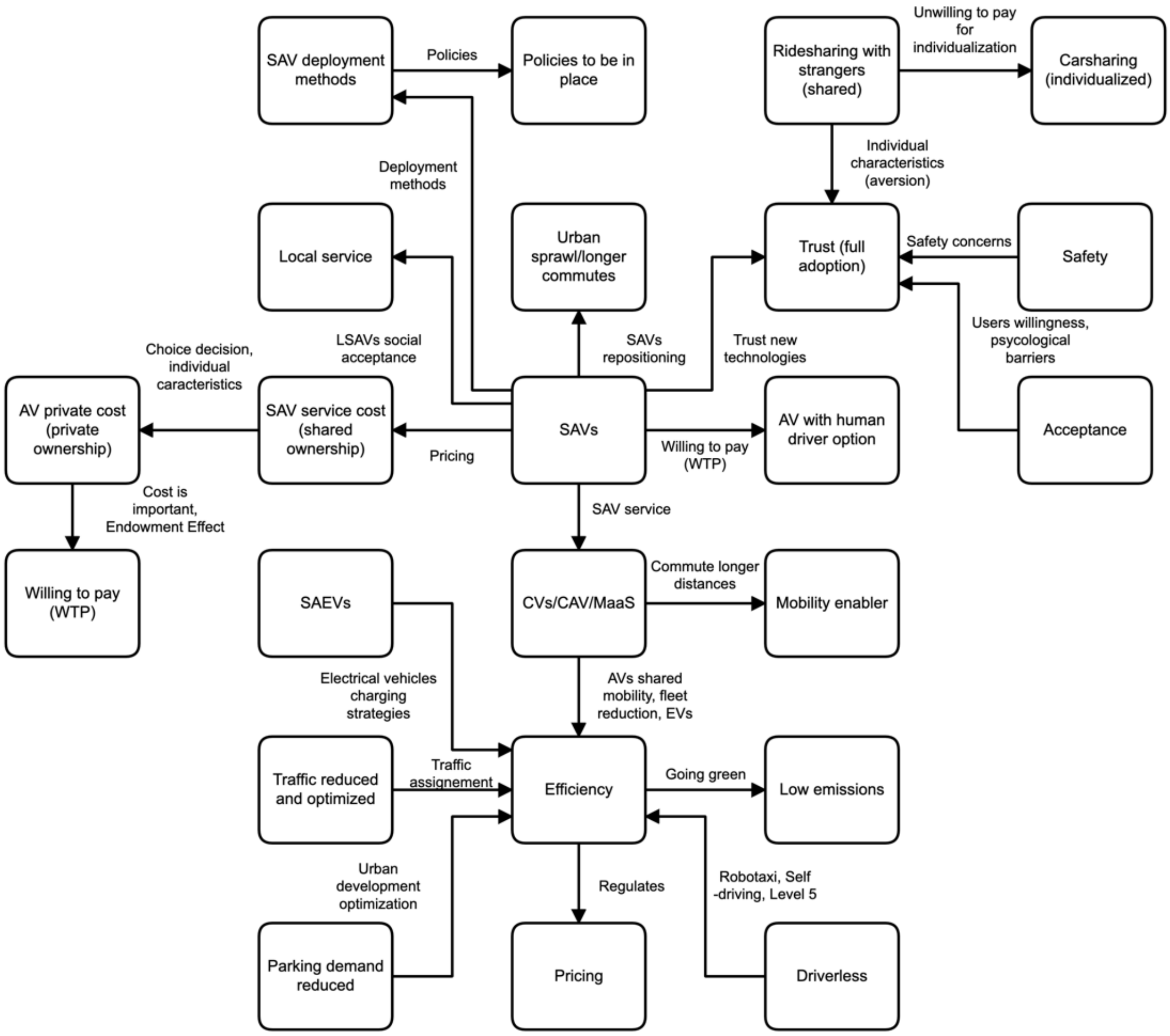


Fig. 7 – Concepts and Relations map

In Fig. 7, it is presented a diagram evolving these main topics and key concepts found in SLR, including favourable and unfavourable arguments regarding SAV concept adoption, as well as social/psychological impact on society and urban efficiency improvement.

4.4 Discussion

In recent years, enabled by the development of information and communication technologies, DRS has received increasing attention. DRS allows shared rides to form on short notice and among strangers who do not know each other's trip itinerary. The higher flexibility of DRS offers additional opportunities to maximize sharing benefits and improve system efficiency [7].

AVs and SAVs will affect people's mobility and the community's traffic conditions. In terms of congestion, it is not clear whether the benefits of increased accessibility and more efficient traffic flows will compensate for the cost of more trip-making and longer distances travelled. Congestion pricing schemes represent an opportunity to internalize the negative costs of traffic congestion [8].

In this study, it was evaluated the possible gains in parking demand if a significant number of commuters switched from private cars to shared or self-driving vehicles. We focused explicitly on homework commuting, as these trips contribute to a large portion of traffic, are highly unbalanced and reserved parking at home and work locations take up a huge amount of space in cities. We can expect the adoption of shared self-driving cars to take up much faster once the technology is deployed on commercial scales. Thus, we can expect that large areas which are currently dedicated to parking will be freed up soon. We note that repurposing existing infrastructure, especially underground parking facilities, can be challenging. On the other hand, repurposing of existing parking spaces can be especially attractive for logistics and light industrial use, which currently cannot afford such central locations [10].

Some consumers might think that an SAV service is a costly option where ride-sharing firms would charge the price plus a profit. These preferences regarding AV modes might change over time when a substantial majority of vehicles on road networks are SAVs. Initially, consumers might opt for a few SAV rides just to see how they like it and to develop trust in the technology at an early stage. However, the findings of this study show that consumers are more likely to use their traditional vehicle as compared to all the AV-related modes during the early transition phase of AV operations, which could be due to the control that users enjoy having a traditional vehicle [12].

A commonly held speculation regarding AV technology is that it is a mobility enabler for elderly travelers and could attract ageing seniors. People more than 55 years old were more likely to use their traditional vehicle compared to adopting the AV options. Travelers of this age group tend to resist changes that could cause a revolutionary transformation in their familiar lifestyles. Nevertheless, this trend could change with increased AV reliability and awareness. This result also could be suggestive of the possibility of distant housing locations adding to the urban sprawl and vehicle-miles-travelled due to consumers' propensity to commute longer distances with AVs [12].

It is important to refer to optimal price-setting strategies for SAVs and conventional (driver-controlled) private cars (CCs) to prevent excessive use of transport resources. Following the concept of Pigouvian taxation, the system welfare is maximized by internalizing so-called external effects. By adding the external costs to the generalized travel costs, the decision-relevant travel costs are corrected and reflect the full costs associated with the usage of transport resources. The Pigouvian taxation principle should be applied to all types of road users, including both CCs as well as SAVs. A world with (S) AVs creates new opportunities for traffic planners and policymakers [13] [14].

Self-driving mobility offers a bright future, but only if governments will be able to overcome the current psychological barriers (in addition to the technological and normative ones), this new technology will obtain a massive diffusion in the market. Governments will define which measures/policies can increase acceptability, almost in the spirit of looking for a placebo that may do little for "real" risk but do much to reduce fear. Autonomous vehicles are not (and never will be) infallible. Therefore, regulators and politicians must play a significant role in managing the acceptability of driverless mobility. Shifting the discussion from the relative risk of injury to absolute risk for society may well allow the psychological barriers to be overcome [16].

The main barrier standing in the path of mass adoption of fully self-driving vehicles may be psychological as well as technological. Furthermore, the acceptability value estimated may not only be an a priori unwillingness to pay. Because autonomous vehicles acceptability is linked also to the social dilemma, it could partially remain also in the acceptance phase, leaving a quota of unwillingness to pay if the governments and manufacturers will only partially solve the ethical dilemma. Only future real case applications and new research will answer these issues. Future research (involving many scientific areas) will also have to solve how to overcome these psychological barriers to trust in this new technology, in addition to the yet unresolved problems of a technological, legislative, and ethical nature [16].

Pronounced growth in rates of vehicle ownership around the world continues to perpetuate a series of economic and environmental issues. Carsharing has received substantial interest in the last few decades as a potential solution to these issues. Despite carsharing's promise on these fronts, there have been limited quantitative studies investigating the impacts of carsharing and SAVs on vehicle ownership. Education programs could be provided to consumers to increase their awareness of carsharing and to experience the service, based on the advice from other studies. In addition, to facilitate carsharing adoption, more innovative and creative ways (e.g., MaaS) are expected to attract consumers. Combing necessary education, trial programs and more efficient and optimized schemes, the adoption of carsharing might be effectively increased [17].

Full automation could potentially lead to a much wider range of impacts, whose benefits to society are, at best, uncertain. If the driving task is removed, time spent driving can be used for other purposes, leading to a reduction in the implicit value of travelling time. This, in turn, could make private car use more attractive than public transport, walking and cycling, resulting in substantial changes in modal shares, and potentially encouraging urban sprawl. If, as envisaged, empty vehicles can return autonomously to low-cost suburban parking areas, this could accentuate the pressures for urban sprawl while making city centre space available for more intensive development; moreover, it would add substantially to traffic flow, thus reducing the benefits of capacity enhancement. The increases in car-km suggest that, with other things equal, the environment will be adversely affected. The decline in person-km by public transport suggests a loss in accessibility for those dependent on it; the decline for walking and cycling implies a loss in the health benefits which these modes afford, while the increase in person-km per capita suggests a tendency to urban extension [18].

The direct effects of connected and autonomous vehicles (CAVs) will positively impact cities. CAVs can influence the optimal structure of a city in two aspects. The city will require less road supply. These savings are more significant with circular road supply than in radial roads. This reduction will allow agencies to manage this infrastructure better. Traffic congestion with CAVs decreases even with less road infrastructure [19].

Despite this, not all the expected effects are positive. Indirect effects will mitigate the direct effects because the reduction of road capacity is not the only factor of importance. Several significant conclusions can be drawn from the results of this work. Firstly, the value of travel time is another crucial factor. On the one hand, it can reduce a third of the total cost; on the other hand, it might cause other significant externalities explained in the following points. Secondly, induced demand is another element that might limit the benefits obtained through CAVs [19].

Thirdly, the increment of vehicle kilometers travelled is a difficult factor to measure, but the consequences can be substantial over the city. Finally, the dispersion of cities is a factor that has not received as much attention, less researched than other impacts of AVs. Thus, urban growth could be more significant than other factors, such as induced demand. Moreover, these changes will boost the operation of new technologies, such as shared autonomous vehicles (SAV) and mobility as a service (MaaS) [19].

The implementation of an innovative solution (designed by experts) needs public acceptance to be successful in the long term, and social acceptance becomes a key factor affecting the time between the introduction of a new concept and its actual implementation. In social psychology, 'social influence' is a "change in an individual's thoughts, feelings, attitudes, or behaviors that results from interaction with another individual or a group". Social influence is, therefore, an important factor for the intention to use an LSAVS by an individual. The findings revealed citizens to have strong and positive aspirations for the deployment of AV technologies, in particular requiring that they provide new accessibility solutions that will be available to all, reduce rather than increase the local and global environmental problems faced by society at large, address inequalities in safety and security whilst travelling and offer solutions relevant for social inclusion policies, such as tackling isolation amongst older people. Similarly, expectations regarding safety and security were that the system would be on a par with aviation or rail travel, even though, unlike those other modes, LSAVs would need to interact with other vehicles, road users and street users [20].

CV uses the vehicle to everything (V2X) communication technology to communicate with other road users and networks, including vehicle to vehicle (V2V), vehicle to pedestrian (V2P) and vehicle to infrastructure (V2I). CV can transmit context-aware messages (CAM) between vehicles to exchange host vehicles speed, heading and brake status via dedicated short-range communications (DSRC). They can help warn drivers of impending crashes and hazards [21].

The availability of an option to retain human driving capabilities in AVs affects the level of adoption and the share of total VMT, due to the willingness to pay (WTP) for AVs, being higher if it includes a human-driven option. This presents a potential dilemma for policymakers and AV manufacturers. The potential safety, congestion and emissions impact may make it advantageous to accelerate the adoption of AVs as quickly as possible if those effects are determined to provide an overall benefit. However, if many AVs are equipped with the capability for human-driving, a significant amount of VMT in AVs may be human-driven, negating a portion of the benefits of shifting the fleets toward AVs. The average respondent indicated an intention to use AV mode for only 35.9% of travel miles if using a vehicle that is capable of both human and self-driving modes, which will result in a lower overall percentage of VMT in autonomous mode if the human-driven option is retained for AVs, regardless of the price premium scenario [22].

There is also a substantial inconvenience cost associated with using pooled or shared automated ride services. This confirms the previous strand of findings on people's aversion to sharing rides with strangers and seriously questions the potential of pooled automated ride services to reduce congestion or carbon emissions in an autonomous vehicle future, as is often mentioned. This survey was conducted before the COVID19 pandemic, and this aversion to pooled ride services has certainly increased even more now, although the longer-term impact is still unclear [23].

The single-car sharing mode was found to be the main mode in the first competition stage, a fusion mode SAVs and shared electrical vehicles (SEVs) was found to be the main carsharing pattern in the second diffusion stage, and the integration of the different modes (SAEVs) was found to be the third shift stage on the carsharing development path. The technologies preceding the shift stage were the basis for the subsequent developments, and a paradigm shift is expected from the integrated mode disruptive technologies, which could break through the limitations of the shift stage and lead to a paradigm shift to a sustainable, connected autonomous shared electric vehicles (CASE) mobility integration framework [26].

The mobility solutions are swiftly deploying new forms of vehicle-sharing, ride-sharing/lift-sharing, and ride-hailing services that are changing the vehicle's ownership model, transforming the demand throughout the day, improving access to mobility by lowering the resources to participate and increasing utilization rates of the individual vehicles and vehicle fleets assets. The vehicles require high security and privacy protection at the component, embedded software and system-level to provide shared mobility solutions. The term "shared" has an additional meaning for the future vehicles, which is connected to sharing resources inside the vehicles and outside the vehicle with other vehicles, other participants in the traffic, with the infrastructure, sharing the data with the mobility stakeholders, sharing services, the computing, sensing, storage and learning capabilities [31].

As mentioned before, trust issue with strangers is one of the primary concerns discouraging people from using ride-sourcing services, consistent with findings of the literature. Regarding perceived benefits and concerns of shared mobility, results showed that those who believed in shared mobility's cost-effectiveness were less inclined to choose exclusive rides. In contrast, those who have concerns about higher travel times were more likely to choose exclusive ride services than other modes [32].

The development of autonomous vehicles is a gradual process within which a mix of human-driven and driverless vehicles is expected over a certain period. New mobility options such as autonomous vehicles (AVs), car sharing and shared AVs have been seen as promising to potentially provide solutions to some of our most intractable problems, like traffic congestion, crashes and wasteful use of urban spaces. Nonetheless, the success of new mobility options is closely associated with the choice behavior of individual people, such as purchasing an AV, using carsharing, using a shared AV and a traditional car. People, in general, intend to keep their current cars or buy an AV, compared to using shared cars. The probability of using shared AVs largely depends on the operational cost and hourly rate and also vehicle availability and access time [34]. When adopting a shared autonomous vehicles (SAVs) service, there is a general lack of studies on the impacts on society (social and psychological) and also urban optimization.

5 Proposed SAV Ontology

The seven main phases in ontology development 101 methodology [4] are going to be implemented in this reference ontology, as well as ontology testing by instantiation.

The Ontology Development 101 method, which is a methodology for ontology development, consists in the execution of seven steps. It starts by determining the domain and scope of the ontology using mainly competency questions. After that, step two suggests verifying if it’s possible to reuse existing ontologies because “almost always worth considering what someone else has done and checking if we can refine and extend existing sources for our particular domain and task”. In step three the important terms in the ontology must be enumerated. The following step (step four) consists in defining the classes and the class hierarchy, using top-down, bottom-up, or mixed approaches. In the next step (step 5), the properties of each class are stated as slots, and in step six the facets of the slots must be defined. The last step is the creation of the instances.

5.1 Step1 - Determine the domain and scope of the ontology

• What is the domain that the ontology will cover? For what are we going to use the ontology?

First, it is necessary to identify the ontology's purpose and its intended uses. This ontology will cover the main shared autonomous vehicles concepts and relations among them. Our main goal is to define a reference ontology that will provide a holistic understanding of the shared autonomous vehicles domain. This research will be approached from two angles, technical/efficiency environment, and social/psychological impacts on users. This approach will be useful to describe the principal concepts within the SAV ecosystem and all the impacts on its surroundings of it, such as the impacts on society functioning.

The aim of the ontology is to provide answers to the following competence questions (CQs):

- **CQ1:** Which are the key concepts regarding Shared Autonomous Vehicles (SAVs)?
- **CQ2:** What are the most important relations among them?
- **CQ3:** What impact on efficiency will SAVs bring to our society?
- **CQ4:** How could traffic optimization benefit from SAVs?

5.2 Step2 - Consider reusing existing ontologies

Existing ontologies, ontological conceptual patterns and foundational ontologies are important resources to reuse [4]. Moreover, reusing existing ontologies may be a requirement if an ontology needs to interact with particular ontologies or controlled vocabularies [2], which is not this research case. To the best of our knowledge and following the SLR process, it was not possible to identify other wide-ranging ontologies for reuse related to the majority of competency questions that were enumerated.

5.3 Step3 - Enumerate important terms in the ontology

The next step is the ontology capture and formalization phase, where the relevant concepts and relations should be identified and organized. This phase should be guided by research questions. The domain for this ontology is quite vast, causing the separation of the ontology into two modules: a module concerning the physical environment surrounding SAVs (i.e., technical, urban optimization and efficiency) and the other concerning the social environment (i.e., the impacts SAVs will have on Society). We will use the Protégé tool which is an open-source, Java-based knowledge-modelling platform. The core of the application is the ontology editor with its graphical user interface (GUI), which allows the user to construct a domain ontology, customize the automatically generated data entry forms and enter data.

It was summarized the terms and their descriptions, generating a dictionary of terms described in Table.6, as suggested by [4].

Table 6 - Important terms definition in the ontology

Concept	Abbrev.	Definition	Reference
Advanced driver assistance systems	ADAS	ADAS are systems that support driving and reduce accidents. Equipped with different sensors and advanced data processing algorithms, ADAS warn drivers of impending danger so that the drivers can take corrective action, or even intervene on the driver's behalf. It can provide many enhanced safety features such as blind spot detection and forward collision warning (FCW).	[21]
Autonomous vehicle	AV	Autonomous vehicle means any vehicle equipped with technology that is a combination of both hardware and software that has the capability of performing the dynamic driving task without the active physical control or monitoring of a natural person whether or not the technology is engaged, excluding vehicles equipped with one or more systems that enhance safety or provide driver assistance but are not capable of driving or operating the vehicle without the active physical control or monitoring of a human.	State of California Department of Motor vehicles (dmv.ca.gov)
Carsharing (ridepooling, ridehailing, carpooling)		Car sharing means the practice where a number of people share the use of one or more cars that are owned by a profit or non-profit carsharing organization and where such organization may require that use of cars to be reserved in advance, charge fees based on time and/or kilometres driven, and set membership requirements of the carsharing organization, including the payment of a membership fee that may or may not be refundable;	City of Toronto (Toronto.ca)
Connected Autonomous Shared Electrical (CASE) Vehicle	CASE	The single carsharing mode was found to be the main mode in the first competition stage, a fusion mode (SAVs and SEVs) was found to be the main car sharing pattern in the second diffusion stage, and the integration of the different modes (SAEVs) was found to be the third shift stage on the carsharing development path. The technologies preceding the shift stage were the basis for the subsequent developments and a paradigm shift is expected from the integrated mode disruptive technologies, which could break through the limitations of the shift stage and lead to a paradigm shift to a sustainable CASE mobility integration framework. The future carsharing automotive trend is an integration of the connected, autonomous, shared, electric vehicles (CASE), which still requires support from different parties such as the government, the market and the public.	[26]
Cooperative Connected AV	CAV	The idea of cooperative CAV is motivated by the observation that vehicles are increasingly intelligent and powerful with various levels of driving assistance functionalities. They are enabled by more sensing and computing resources. These sensor and computing resources of CAV vehicles and the transport infrastructure could be shared and exploited. With resource sharing and cooperation CAVs can have comprehensive perception of driving environments, and novel cooperative applications can be developed to improve road safety and efficiency (RSE). The key feature of the cooperative CAV system is the cooperation within and across the key players in the road transport systems and across system layers.	[21]
Connected vehicle	CV	CV uses vehicle to everything (V2X) communication technology to communicate with other road users and networks, including V2V, V2P and V2I. Recently there are increasing research and standardization efforts in 3GPP to provide cellular V2X with low latency and high data rate communications.	[21]
Context aware messages	CAM	CV can transmit context aware messages (CAM) between vehicles to exchange host vehicles speed, heading and brake status via dedicated short-range communications (DSRC). They can help warn drivers of impending crashes and hazards.	[21]
Dedicated short range communications	DSRC	The DSRC Service involves vehicle-to-vehicle and vehicle-to-infrastructure communications, helping to protect the safety of the traveling public. It can save lives by warning drivers of an impending dangerous condition or event in time to take corrective or evasive actions. The band is also eligible for use by non-public safety entities for commercial or private DSRC operations.	Federal Communications Commission FCC (fcc.gov)
Driverless (self-driving, autopilot, robotaxi, shuttle)		Automated driving aims specifically to reduce road accidents, alleviate traffic congestion, abate pollutant emissions and reduce fuel consumption (European Commission, 2011). Self-driving vehicles (also called "driverless" or Autonomous Vehicles - AVs) could significantly change the concept and limits of mobility services, improving mobility for those who cannot drive because of their youth, old age, disability or incapability.	[16]
Dynamic ride sharing	DRS	Fully self-driving vehicles, once they become available, can be adopted with or without a human driving option and can be owned privately or shared by multiple users. If self-driving vehicles are shared, they can be dynamically shared among the users by matching them in real-time. Dynamic ride sharing (DRS) has become possible with smartphone applications and network technologies, while non-DRS represents traditional matching of users for car-pooling.	[22]
E-mobility		Electro mobility (or e-Mobility) represents the concept of using electric powertrain technologies, in-vehicle information, and communication technologies and connected infrastructures to enable the electric propulsion of vehicles and fleets. Powertrain technologies include full electric vehicles and plug-in hybrids, as well as hydrogen fuel cell vehicles that convert hydrogen into electricity. e-Mobility efforts are motivated by the need to address corporate fuel efficiency and emission requirements, as well as market demands for lower operational costs.	Gartner IT Glossary
Electrical vehicle	EV	An EV is a shortened acronym for an electric vehicle. EVs are vehicles that are either partially or fully powered on electric power. Electric vehicles have low running costs as they have less moving parts for maintaining and also very environmentally friendly as they use little or no fossil fuels (petrol or diesel). While some EVs used lead acid or nickel metal hydride batteries, the standard for modern battery electric vehicles is now considered to be lithium-ion batteries as they have a greater longevity and are excellent at retaining energy, with a self-discharge rate of just 5% per month. Despite this improved efficiency, there are still challenges with these batteries as they can experience thermal runaway, which have, for example, caused fires or explosions in the Tesla model S, although efforts have been made to improve the safety of these batteries.	TWI Ltd UK (twi-global.com)
Empty VMT	eVMT	Shared mobility is on the horizon and policy must be developed to tackle initial and future large-scale adoption of SAVs. Regions with urban sprawl, like Chicago, are expected to have high percentages of eVMT (empty or unoccupied VMT in an SAV) arising from longer-than-average trip distances when servicing the exurban areas.	[28]
Endowment effect		A theoretical complication with a potential transition away from private ownership of the vehicle is termed the endowment effect, which finds that people sometimes value ownership of a commodity more than their willingness-to-pay (WTP) for it. In the case of AV, this means a shift to shared vehicles may require a utility benefit greater than expected based solely on the characteristics of the alternative modes.	[9]
Ghost trips		AVs will move without passengers ("ghost trips") increasing VMT/VKT.	[19]
Internet of vehicles	IoV	Internet of Vehicles (IoV) is a subset of IoT that allows an environment where vehicles are equipped with dedicated onboard units capable of communicating with other vehicles (V2V communication) and receiving data services from infrastructure, cellular base stations and Wi-Fi access points regarded as V2I communications.	[38]

Levels of automation (0 to 5)		Automated vehicles are vehicles with some level of automation to assist or replace human control. The Society of Automotive Engineers (SAE) has defined 6 different levels of automated functionality, ranging from no automated features (Level 0) to full automation (Level 5 — commonly referred to as autonomous, self–driving or driverless vehicles).	[5]
Light detection and ranging	LiDAR	The inclusion of non-V2X information received (LiDAR, radar, camera, ultrasonic, inertial sensors) in the development and validation process for performance and test metrics to address the fail-operational operation for autonomous vehicles is required. Several V2X and non-V2X systems must coexist on a vehicle, and validation and test procedures must cover all of them.	[31]
Local SAV	LSAV	Increasing numbers of citizens are choosing not to become car drivers, or are not able to maintain car driver status, because they delay learning to drive, never learn to drive, or, in the context of an ageing population, give up driving for health or ability reasons. Such citizens can be expected to use collective solutions, and LSAVSs can potentially offer 'last mile' connections to public transport bus and rail services, therefore increasing the overall viability of the collective transport network.	[20]
LTE V2X	LTE-V2X	LTE- V2X is used for short-range communications (which provides an ad-hoc network for the unlicensed spectrum 5.9 GHz ITS band, similarly to ITS-G5). See also C-V2X.	[31]
Mobility-as-a-Service	MaaS	To facilitate carsharing adoption, more innovative and creative ways (e.g., MaaS) are expected to attract consumers. Combining necessary education, trial programs and more efficient and optimized schemes, the adoption of car-sharing might be effectively increased.	[17]
On-demand mobility	ODM	On-Demand Mobility (ODM) services quickly emerged to a sizeable market share in a very short time. Considering the fast advancement in autonomous driving, it will soon be a reality that the largest cost component, the driver, will be removed from the business model and consequently, the fast surge in popularity of ODM services is likely to become even more rapid.	[15]
Platooning		A platoon of connected automated vehicles (CAVs) is defined as a group of CAVs that exchange information, so that they can drive in a coordinated way, allowing very small spacings and, still, travelling safely at relatively high speeds.	[40]
Private AV	PAV	The success of new mobility options is closely associated with the choice behavior of individual people, such as purchasing an AV, using car sharing, using a shared AV and a traditional car. Existing studies however did not report sufficiently evidences yet on the preference of people when facing a full set of new mobility options involving AVs, car sharing and SAVs. Understanding further the decision making of individuals in the emerging and autonomous mobility options can improve smart policy making in infrastructure development and planning. It is found that people in general intend to keep their current cars or buy an AV, compared to using shared cars. The probability of using shared AVs largely depend on the operational cost and hourly rate, but also vehicle availability and access time.	[34]
Shared Autonomous EV	SAEV	Car sharing platforms can provide faster application scenarios for emerging technologies such as electric, autonomous or driverless vehicles, which has led to the emergence of SAEV (shared, autonomous, electric vehicles) technologies, each of which has its own advantages and challenges. Electric vehicles reduce the emissions from existing petrol-powered vehicles, autonomous vehicles improve safety and shared mobility provides a more direct way to shape the future, providing affordable, accessible and fair multimodal transport options. This integration of technologies makes SAEV innovations not only economically viable, but also attractive.	[26]
Shared AV	SAV	These new mobility options offer individuals a different way of using vehicles, e.g., shared use versus private use, human-driven versus autonomous driving. Like the peer-to-peer concept of carsharing, where the idle time of a private car is shared with others, an AV can probably popularize the market share of shared car use because AVs are not bounded by drivers. The concept of shared AV (SAV) is in line with the definition of sharing economy in terms of sharing idle space and time. It was found that one shared AV can replace around ten conventional vehicles. Although this does not necessarily lead to a reduced traffic flow on urban roads, it shows great potential to change our way of travel from privately owned vehicles to shared cars. Individuals who want to use autonomous vehicles but cannot afford them can use shared AVs without the need of looking for a traditionally shared car, because the vehicle moves itself to the place where people stay.	[34]
Shared EV	SEV	Because electric vehicles (EVs) have low to no emissions, they can positively impact both urban air pollution and human health. Consequently, many countries are accelerating the adoption of EV to mitigate air quality, climate change and energy security concerns. Therefore, electric vehicles are well-suited for shared car systems because the trips are usually short to mid-range, which allows the cars to recharge when idle.	[26]
Unlicenced V2X	U-V2X	The unlicensed V2X (U-V2X) is based on the IEEE 802.11p/bd technology, such as ITS- G5 in Europe, which in built on WLAN and provides an ad-hoc network for the 5.9GHz ITS band. The incumbent wireless communication technology ITS-G5 is already deployed for safety services in the 5.9 GHz band. In 2019, 6,000 km of roads were already equipped with roadside units (RSUs) facilitating safety using cellular connectivity and ITS-G5. Since March 2020, ITS-G5 supporting road traffic safety is a default feature of the VW Golf 8 and the VW ID models. By the end of 2021, roughly 750 000 Golf 8 and IDs are expected to reach the European market.	[31]
Urban sprawl		Fully automated cars are likely to appear on public roads within the next decade. They are being promoted as ways of improving network capacity and reliability, making car use available to a wider range of people and reducing accidents. However, several researchers have suggested that they could lead to a significant increase in car use, with a parallel reduction in walking, cycling and public transport, and that this could more than offset the benefits of capacity increases and lead to urban sprawl.	[18]
Value of travel time savings	VTTS	The concept of VTTS reflects the reality, derived from microeconomic theory, that people take transport decisions in the context of a constrained time budget – this constraint determines how people choose whether they spend their time on one activity or on another, and how much they would pay to avoid having to spend time on a particular activity. The subjective VTTS is therefore defined as the willingness to pay for one unit of travel time saving. In the context of autonomous driving, it is reasonable to assume that the perception of time spent in a vehicle might change (from present-day values) in a positive way – that is, the VTTS for autonomous driving might decrease (i.e., the disutility of travel time become less negative).	[11]
Vehicle miles/kms travelled	VMT/VKT	Shared and autonomous vehicle technologies may also change the US fleet composition, since SAVs may alter vehicle ownership and demand for various transportation modes. Autonomous vehicle (AV) travel may partially replace airline travel, while generating more short-distance travel. It stands to reason that intercity rail and bus modes may also be affected. Each shared autonomous vehicle may replace 11 personal vehicles but increase vehicle-miles traveled (VMT) by 10%, while decreasing overall emissions. If SAVs entice people to give up personal vehicles, the vehicle fleet may shrink, necessitating less parking space. Increased VMT of SAVs may drive higher vehicle production rates of SAVs, since they will accumulate miles quickly. Thus, the adoption of SAVs would derive different travel characteristics for US vehicle fleets in the future.	[22]
Celular V2X	C-V2X	Cellular V2X (C-V2X) is an umbrella term that includes LTE- V2X for short-range communications (which provides an ad-hoc network for the unlicensed spectrum 5.9 GHz ITS band, similarly to ITS-G5), and the cellular network communications (LTE Uu) for long-range communications. The 3GPP GPP3 (2018) has specified the cellular C-V2X in different releases	[31]

		(Rel.14/15/16). C-V2X technology supports additional operation modes and will provide increased throughput in the new 5G NR version adopted in Rel.16. The C-V2X will provide increased environmental perception to enable sensor-data sharing among vehicles and infrastructures. It could enhance the automated driving control, allowing the vehicle's cooperation by the perception and the control subsystems of 5G.	
Vehicle-to-Everything (V2X)	V2X	Wireless communication between vehicle and Infrastructure, Network, Pedestrians/cyclists, Vehicle, Cloud/Edge, etc.	[31]
Vehicle-to-Infrastructure (V2I)	V2I	Wireless communication between vehicle and roadside units (RSUs), external communication devices/ platforms and traffic facilities.	[31]
Vehicle-to-Network	V2N	Wireless communication between vehicle and cellular networks, (e.g., value-added services).	[31]
Vehicle-to-Pedestrian/cyclists (V2P)	V2P	Wireless communication between vehicle and vulnerable road users (VRUs) (e.g., safety-related services).	[31]
Vehicle-to-Vehicle (V2V)	V2V	Communication between mobile vehicles (e.g., surrounding vehicles position).	[31]
Vehicle-to-Body (V2B)	V2B	Internal information transmission.	[31]
Vehicle-to-Cloud/Edge (V2C)	V2C	Wireless communication between vehicle and the cloud or edge computing centers.	[31]
Vehicle-to-Device (V2D)	V2D	Short-range wireless communication between the vehicle and devices (IoT) either inside or outside the vehicle.	[31]
Vehicle-to-Grid (V2G)	V2G	Wired/wireless communication between electric vehicle and the charging station/power grid.	[31]
Vehicle-to-Home (V2H)	V2H	Wireless communication between vehicle and a fixed or temporarily home (e.g., real-time routing).	[31]
Vehicle-to-Maintenance (V2M)	V2M	Wireless between the vehicle and the vehicle condition responsible (e.g., automotive manufacturer, repair shop), including vehicle condition monitoring, predictive maintenance notification or alerts.	[31]
Vehicle-to-Network (V2N)	V2N	Wireless communication between vehicle and cellular networks, (e.g., value-added services).	[31]
Vehicle-to-Owner (V2O)	V2O	Wireless communication between vehicles and its owner (e.g., car rental, fleet management, freight tracking).	[31]
Vehicle-to-Users (V2U)	V2U	Wired/wireless exchange of information between the vehicle and its current user including situational information.	[31]
Vehicular cloud computing	VCC	Vehicular networking has become a significant research area due to its specific features and applications such as standardization, efficient traffic management, road safety and infotainment. Vehicles are expected to carry relatively more communication systems, on board computing facilities, storage and increased sensing power. Hence, several technologies have been deployed to maintain and promote Intelligent Transportation Systems (ITS).	[39]

5.4 Step4 - Define the classes and the class hierarchy

Using the theoretical background described in the Step3, the class hierarchy was designed. As suggested by [2], this taxonomy uses the top-down approach. This approach helps to define the more salient concepts first, and then generalize and specialize them properly. The class hierarchy diagram is depicted in Fig. 8 and Fig. 9, with diagrams in Fig. 10 and Fig. 11. The ontology was developed using Protégé tool version 5.5.0. Was also defined in this research two sub-ontologies, the first one describing the ecosystem efficiency, and the second one the social impact in society by SAVs.

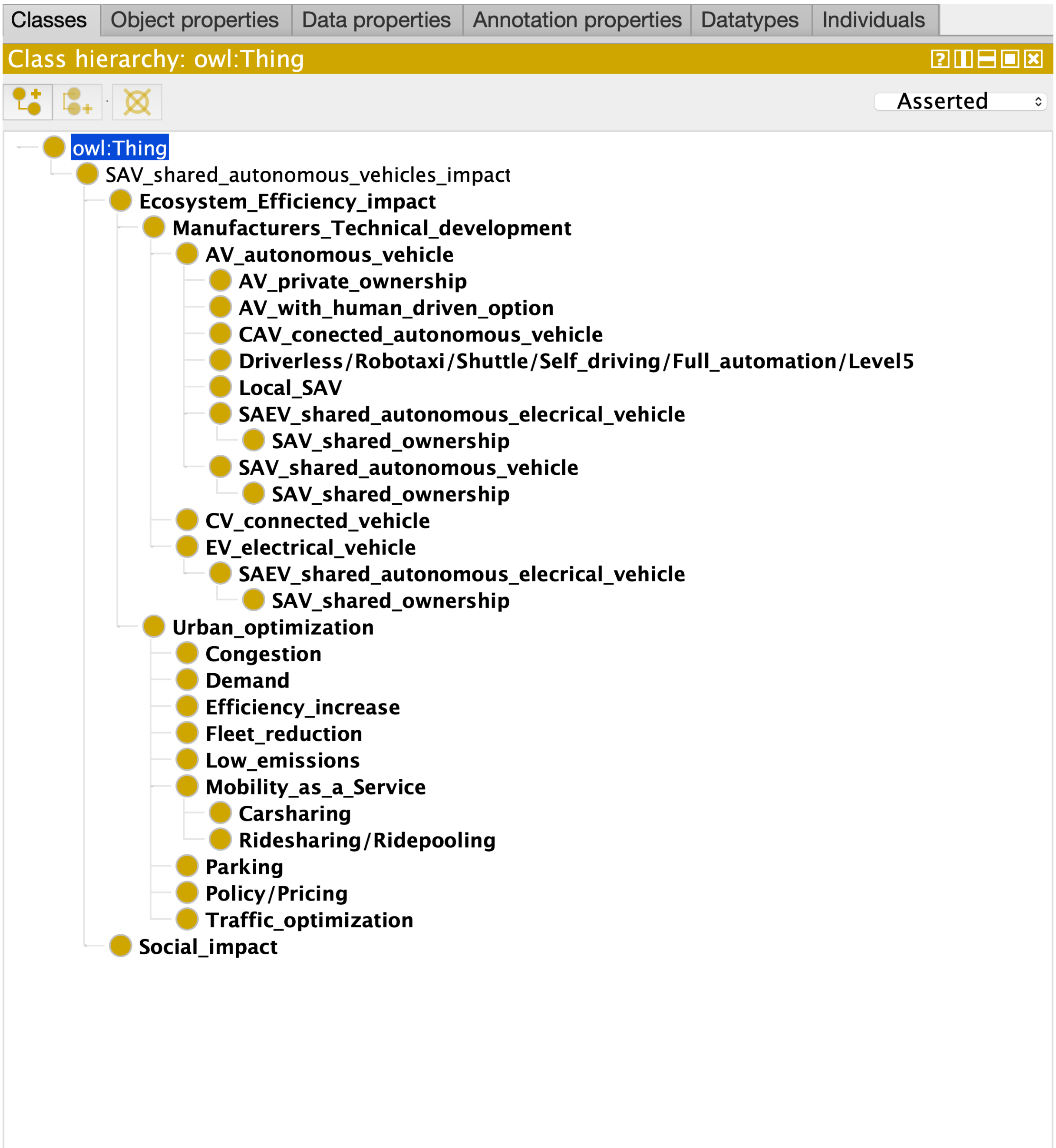


Fig. 8 - Taxonomy of shared autonomous vehicles impact – Ecosystem Efficiency

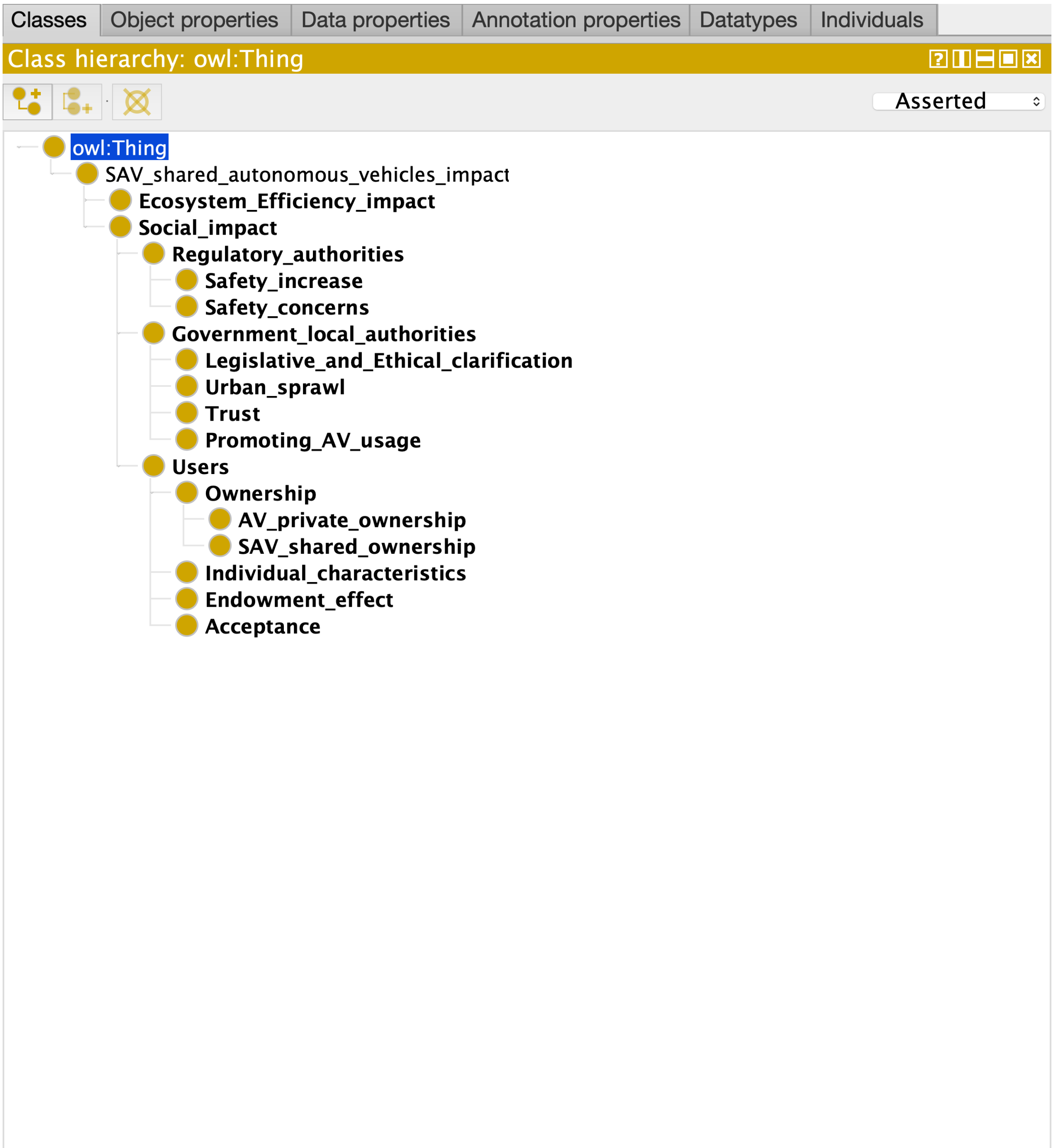


Fig. 9 - Taxonomy of shared autonomous vehicles impact – Social

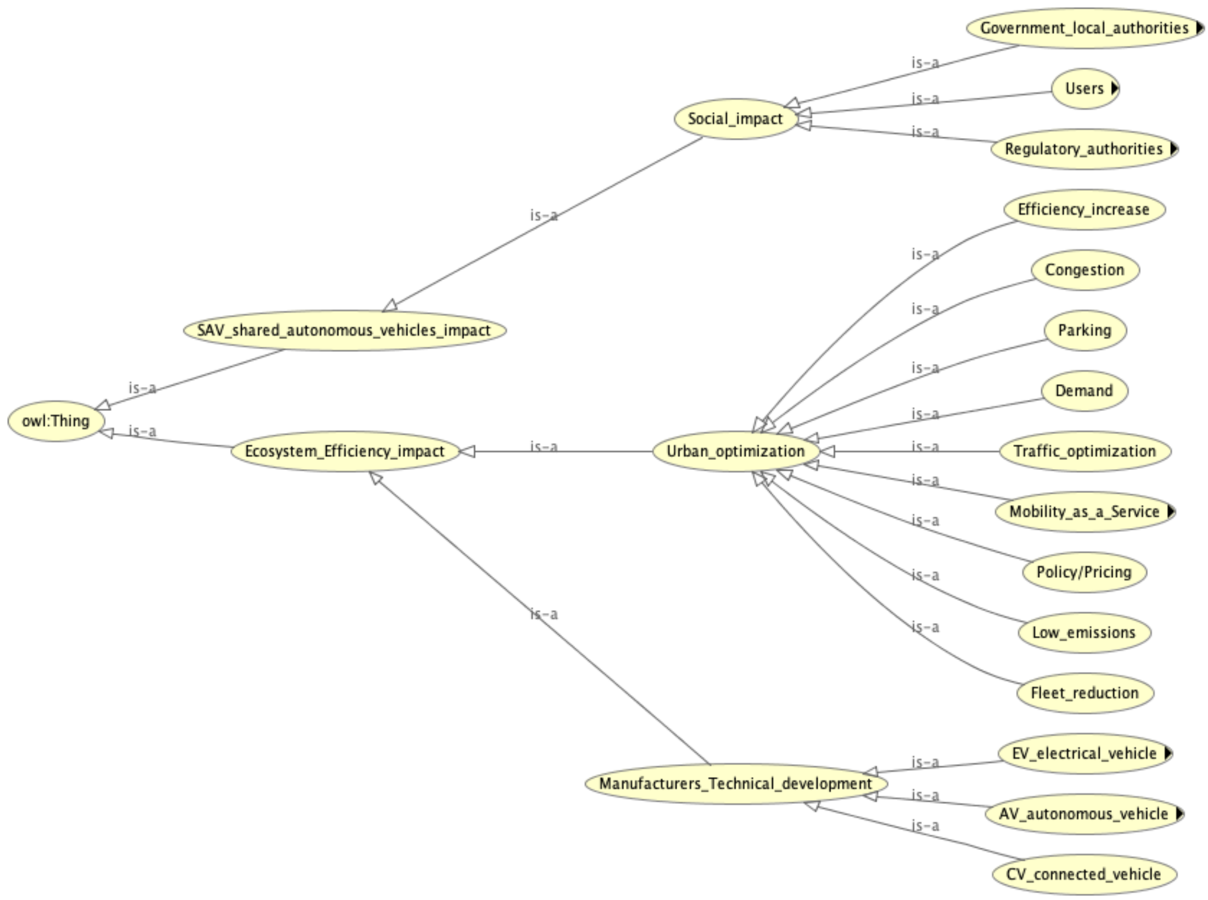


Fig. 10 - Taxonomy of shared autonomous vehicles impact - diagram

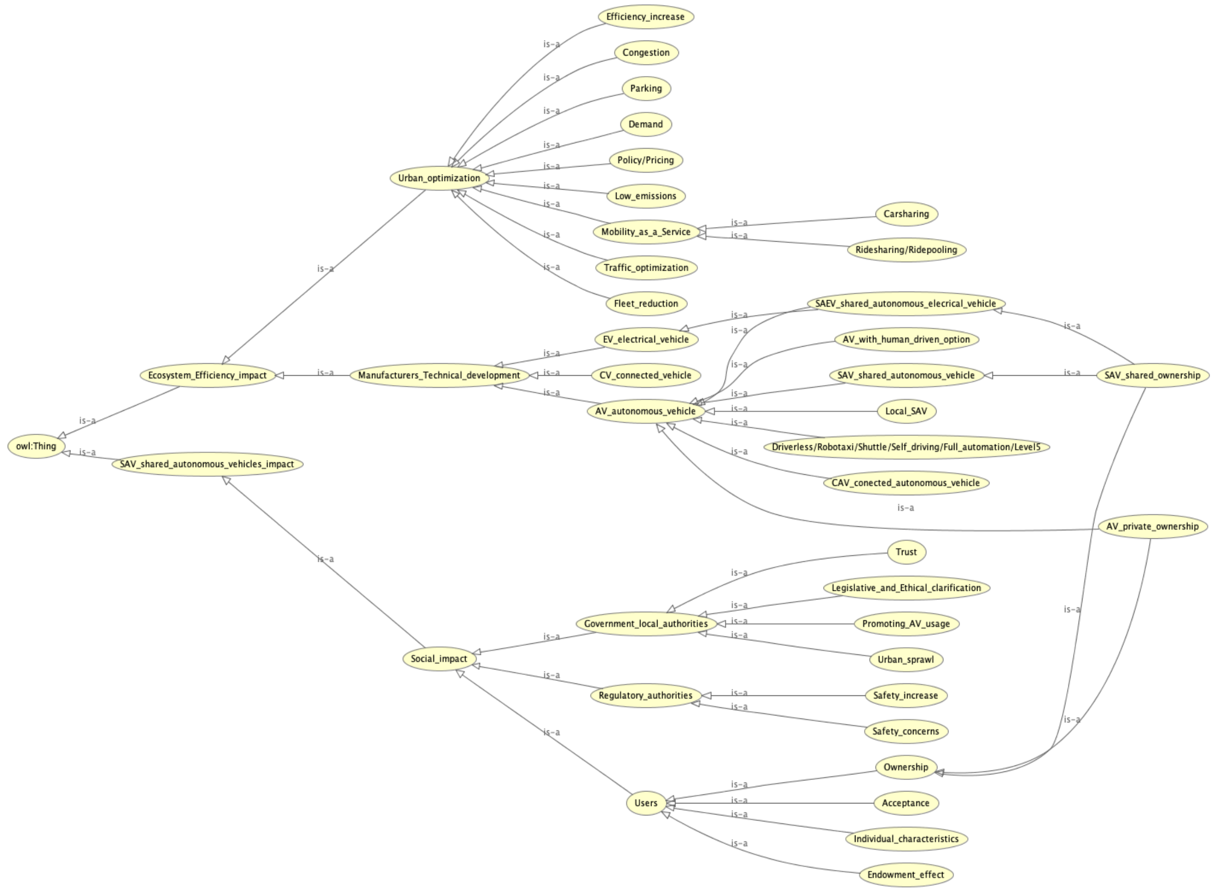


Fig. 11 - Taxonomy of shared autonomous vehicles detailed impact- diagram

5.5 Step 5 - Define the properties of classes - slots

According to [2], classes will not only provide enough information to answer the competency questions from step1, but should also provide the internal structure of concepts and their properties. These properties become slots attached to classes. A slot should be attached at the most general class that can have that property. Slots are the properties of each concept describing the various features and attributes of the concept (also roles or properties) and its restrictions (also called role restrictions). An ontology plus a set of individual instances of classes, constitutes a knowledge base. An ontology development includes defining classes in the ontology, arranging the classes in a taxonomic (subclass–superclass) hierarchy, defining slots, describing the allowed values for these slots, and filling in the values for slots/instances.

In Fig.12 we can observe the roles identified in the SLR that show relations between main concepts, each role as its own domain and range as we can observe in Fig.13.

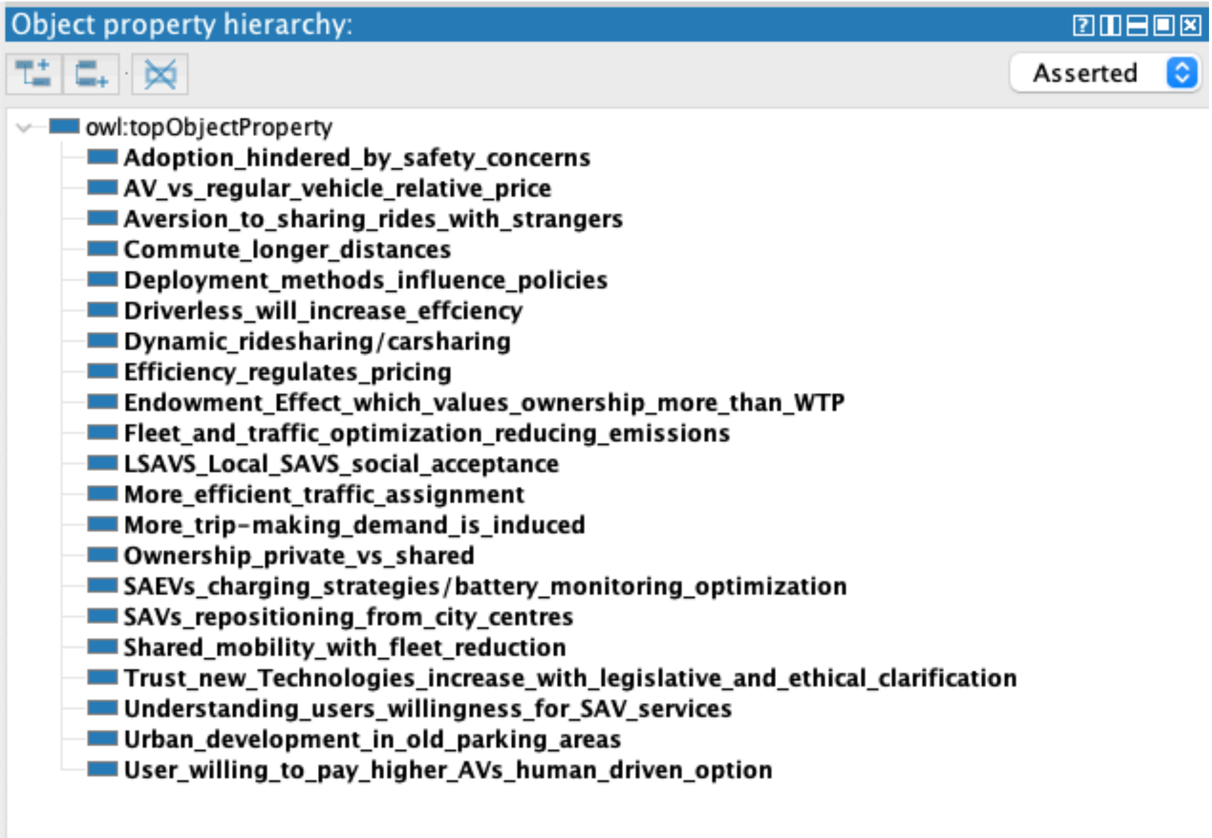
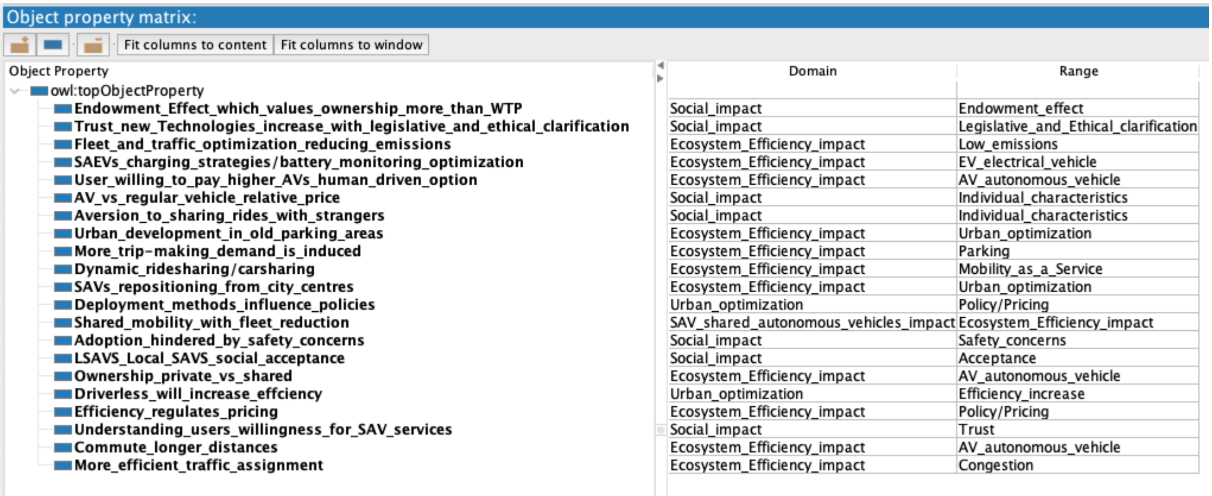


Fig. 12 - Taxonomy of shared autonomous vehicles impact – Concept Properties



Object Property	Domain	Range
owl:topObjectProperty		
Endowment_Effect_which_values_ownership_more_than_WTP	Social_impact	Endowment_effect
Trust_new_Technologies_increase_with_legislative_and_ethical_clarification	Social_impact	Legislative_and_Ethical_clarification
Fleet_and_traffic_optimization_reducing_emissions	Ecosystem_Efficiency_impact	Low_emissions
SAEVs_charging_strategies/battery_monitoring_optimization	Ecosystem_Efficiency_impact	EV_electrical_vehicle
User_willing_to_pay_higher_AVs_human_driven_option	Ecosystem_Efficiency_impact	AV_autonomous_vehicle
AV_vs_regular_vehicle_relative_price	Social_impact	Individual_characteristics
Aversion_to_sharing_rides_with_strangers	Social_impact	Individual_characteristics
Urban_development_in_old_parking_areas	Ecosystem_Efficiency_impact	Urban_optimization
More_trip-making_demand_is_induced	Ecosystem_Efficiency_impact	Parking
Dynamic_ridesharing/carsharing	Ecosystem_Efficiency_impact	Mobility_as_a_Service
SAVs_repositioning_from_city_centres	Ecosystem_Efficiency_impact	Urban_optimization
Deployment_methods_influence_policies	Urban_optimization	Policy/Pricing
Shared_mobility_with_fleet_reduction	SAV_shared_autonomous_vehicles_impact	Ecosystem_Efficiency_impact
Adoption_hindered_by_safety_concerns	Social_impact	Safety_concerns
LSAVS_Local_SAVS_social_acceptance	Social_impact	Acceptance
Ownership_private_vs_shared	Ecosystem_Efficiency_impact	AV_autonomous_vehicle
Driverless_will_increase_effciency	Urban_optimization	Efficiency_increase
Efficiency_regulates_pricing	Ecosystem_Efficiency_impact	Policy/Pricing
Understanding_users_willingness_for_SAV_services	Social_impact	Trust
Commute_longer_distances	Ecosystem_Efficiency_impact	AV_autonomous_vehicle
More_efficient_traffic_assignment	Ecosystem_Efficiency_impact	Congestion

Fig. 13 - Taxonomy of shared autonomous vehicles impact – Concept Properties (detailed)

5.6 Step 6 - Define the facets of the slots

According to [2], slots can have different facets describing the value type, allowed values (domain) and the number of the values (cardinality), among other features (see Fig. 14 for example).

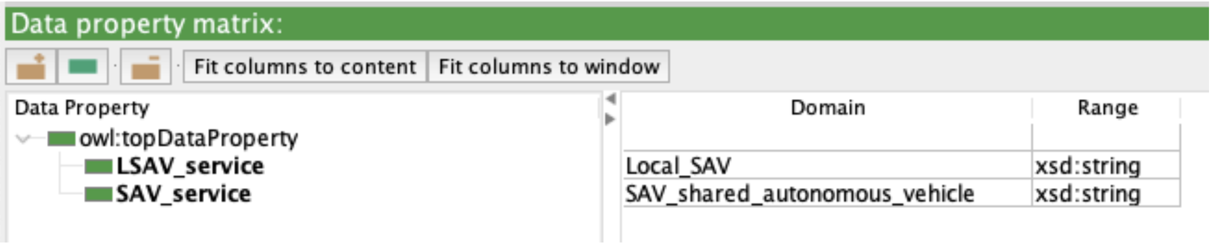


Fig. 14 - Taxonomy of shared autonomous vehicles impact – Concept Data Properties

5.7 Step 7 - Create Instances

According to [2], an evaluation phase is needed to validate the ontology in a real-life situation, in this case that will be fulfilled in GM Cruise SAV deployment in San Francisco USA. That will be detailed in next chapter.

6 Evaluation

The proposed ontology evaluation process is performed using 101 verification and validation methods guided by the raised competency questions (CQs). For the verification step, the concepts and relations between concepts described are important to check the ontology's ability to answer the CQs mentioned before.

The validation aspect will be ensured by the ontology instantiation to illustrate a real-world situation, in our case a real commercial SAV service implementation in San Francisco, USA, the GM Cruise. Described below are the main concepts and relations found:

- **All seeing** - 40+ sensors give Cruise AVs a 360° view to see far and wide and can map the location of surrounding objects within centimeters. These sensors give the AV information about everything nearby, like pedestrians, construction, bikes, other cars, road conditions, and a lot more. The AV makes sense of this information in a split second, tracking its important object. A detailed map of the street helps the car interpret the context of what’s happening [47];
- **Smart thinking** - now that Cruise AV knows what’s happening nearby, it determines the best way to reach its destination by considering multiple paths per second and constantly choosing the best one to meet changing road conditions and events. Cruise AVs evaluate and negotiate the complex movements of the busiest city streets with efficiency and without distraction. Fast acting, Cruise AVs detects, predict and respond to the movement of people, animals and objects faster than any human brain. Always learning, Cruise AVs learn and improve with every drived mile - more than 2m on the hectic streets of San Francisco (and counting) [47];
- **Safer streets** - more than 100 people in the US die in car crashes every day. 94% are caused by human error. Cruise AVs never get distracted, it can’t drive under the influence of alcohol and never get tired [47]. Cleaner air - city air can be as bad as smoking 20 cigarettes a day. Cruise all-electric vehicles are zero-emission and are powered by 100% clean, renewable energy. Increased access, many Americans struggle with access to reliable or affordable transportation. Self-driving services can be a game-changer, allowing millions to join (or re-join) the workforce. Custom built on the foundation of the Chevy Bolt, Cruise first-generation vehicles have logged millions of city miles to make self-driving a reality. They have everything they need to drive directly onboard: 40% of their hardware is unique to self-driving. Reclaimed time, America’s drivers spend over 40 hours a year in traffic. Some much more. Self-driving vehicles won’t just decongest our roads, they’ll give back time and possibility [47];
- **Local SAV (LSAV)** - when a steering wheel, pedals, a rearview mirror, and more, are removed, it is get something new — an experience purely designed around the rider. That means a spacious cabin and an on-demand, consistent experience where people can relax, work or connect [47].

Cruise, the autonomous vehicle unit of GM (General Motors), has finally been given the green light to start charging fares for its driverless robotaxi service in San Francisco, USA (see Fig. 15). The California Public Utilities Commission (CPUC) voted to award Cruise with a driverless deployment permit, the final hurdle needed to jump to begin operating autonomous ride-hail service commercially [41].

Cruise will be operating its passenger service at a maximum speed of 30 miles per hour between the hours of 10 p.m. to 6 a.m. on select streets in San Francisco (see Fig. 16), adding another one and a half hours to its current service. The company will need additional state regulatory approval to charge members of the public for driverless rides in the rest of the city, according to the license. These preconditions come as part of Cruise's "passenger safety plan", that limits the service to overnight hours and doesn't include the city's dense urban core, according to the CPUC's draft resolution [41]. In the coming months, expected end of 2022, Cruise will expand its operating domain, hours of operation and ability to charge members of the public for driverless rides until having fared rides 24/7 across the entire city [41].

Cruise has been offering free driverless rides to San Franciscans in its autonomous Chevrolet Bolts between the hours of 10:30 p.m. to 5 a.m. since February. The company began testing its autonomous vehicles without a driver in the front seat in the city in 2020 and started giving passengers free test rides in June 2021. In October 2021, Cruise received a driverless deployment permit from the California Department of Motor Vehicles, which meant it could begin charging for autonomous vehicle services, like delivery. Crucially, the limits of the DMV's permit stop at charging for robotaxi rides [41].

With this CPUC permit, Cruise is the only AV company in the city that can operate a commercial driverless ride-hailing service. Waymo, Cruise's biggest competitor and the self-driving arm of Alphabet, also recently received a permit from the CPUC to charge for robotaxi, but only if a human safety operator is present during rides. Waymo has been offering a fully autonomous commercial ride-hail service in Chandler, a city southeast of Phoenix, since 2020, and recently expanded its driverless program in the city [41].

A group of San Francisco agencies — including the city's municipal and county transportation authorities, the Bureau of Fire Prevention and Investigation, the Mayor's Office on Disability and the SF Police Department — raised concerns about the lack of clarity within the CPUC's draft resolution regarding limitations to Cruise scaling its fleet. "Cruise's current approach to passenger pickup and drop-off, stopping exclusively in the travel lane even when curb space is available, is below the level expected for human drivers," the comments read, emphasizing the danger that an ever-growing fleet of AVs stopping in the travel lane could pose to vulnerable road users, like emergency responders, people with disabilities and older people and cyclists. While Cruise's CPUC permit allows for a fleet of up to 30 all-electric autonomous vehicles, Cruise has not been shy about promoting its plans to scale rapidly soon with plans for growing its fleet of purpose-built Origin AVs to thousands, even tens of thousands, in the coming years [41].

As part of its comments, the city provided a list of recommendations for the CPUC to integrate into its final resolution, including:

- Clarifying that increases in fleet size and vehicle model require Cruise to submit an advice letter, given Cruise's goals to not only expand its fleet size rapidly but to do so with a new, purpose-built vehicle [41];
- Requiring CPUC staff to post on its website the geographic area in which operation of driverless Cruise AVs is authorized. Cruise currently offers driverless rides for members of the public in about 70% of the city, which is detailed in a rough map CEO Kyle Vogt recently tweeted (see Fig. 17 below), but did not provide the specific areas in which it will charge passengers for driverless rides [41];
- Convening a regular working group to address data collection around pickup and drop-off of customers and AV interactions with first responders and street-based workers in San Francisco [41];
- The CPUC's decision to award Cruise with a deployment permit sets a precedent for how the state will continue to regulate commercial AV services in the future, so feedback from the public is crucial [41].

Fig. 15 - Commercial AV Cruise user. Image crédits: Cruise

Fig. 16 - Screenshot of Cruise's proposed autonomous ride-hail service in San Francisco per CPUC agenda. Image Credits: California Public Utilities Commission

Fig. 17 - Cruise CEO Twitter message – Plans for expansion

Self-driving test cars with human safety drivers have become a constant sight in San Francisco, and completely driverless ones are increasingly common too. Turning them into a fledgling business in a major U.S. city will mark a milestone in the long and delayed journey toward driverless taxi service [42].

The permit was Cruise's final hurdle in California. Cruise said it would launch paid services within the next couple of weeks using up to 30 driverless Chevrolet Bolt electric vehicles. They will not be allowed on highways or at times of heavy fog, precipitation or smoke [42].

Disability and business groups expressed support, and staff for the state commission said Cruise's proposal reasonably protects passenger safety [42]. Citing concerns that unusual behavior by the cars could result in bodily harm, San Francisco fire, police and transit officials wanted state regulators to impose restrictions before allowing Cruise into the ride-hailing business. They recommended requiring further approval to add more cars and a new working group of state and local officials [42].

The local officials said a confused Cruise AV briefly blocked a San Francisco fire engine in April that was responding to a fire alarm, and days earlier a driverless Cruise car stopped by police appeared departed before the officer work was done. Cruise said its cars made safe decisions [42]. While rival Alphabet Inc's (GOOGL.O) Waymo has charged for rides in suburban Phoenix since 2018, Cruise's proposed deployment in its hometown of San Francisco, a more densely populated, hilly and unpredictable area, is considered by tech experts the greater challenge [42].

Waymo has given employees driverless rides in San Francisco since March, and Cruise has offered free late-night test rides to the public since February. But there is also a longstanding issue that self-driving cars cannot always correctly predict how humans will react to changing events, including the actions of the car. Cruise has even given the issue a name, the "couples problem," a former employee said [42].

There were also some accidents and near misses, a decade before California first allowed public testing of self-driving vehicles, smooth rides that follow traffic rules are the norm, but surprises persist [42]. In a public presentation last year, Cruise senior director Brandon Basso described "kinematic uncertainty," a challenge faced by self-driving cars in predicting actions of humans on the road and deciding, for instance, when to yield [42]. Cruise said its vehicles understand complex social dynamics and hedge against uncertainty by taking safe actions. Even the San Francisco officials who challenged the permit said that despite "the conspicuous exceptions, the driverless Cruise AV appears to generally operate as a cautious and compliant defensive driver." [42].

Cruise still operates free of cost driverless rides in the rest of the city (for “a group of power users”) but wants to expand paid rides across the city quickly. Vogt said that “as soon as the end of the year” it may have “hundreds” of vehicles “covering all of San Francisco.” [43].

Vogt points out that Cruise should be able to offer drives cheaper than taxis with drivers in them, because the driver does not need to be paid for their time. So far, Cruise’s paid driverless taxi is less expensive than competing ride-hailing apps, but not by a lot. Cruise said that a trip would cost 90 cents per mile and 40 cents per minute, plus a $5 base fee. For a sample 1.3-mile trip, this would cost a total of $8.72

including taxes, whereas Uber would cost $10.41 for the same trip. So, a cost reduction, sure, but not a tremendous one. Vogt claims that the cost will eventually drop to “far below” the cost of ride-hailing apps today as technology develops, but given that ride-hailing apps currently run at a loss anyway, we don’t really know how the economics of any of this will shake out in the long run [43].

As for the overall social issues with driverless taxis, the value of having your own space as the COVID-19 pandemic continues on or another one arises. Shared transport with strangers is one of the vectors of transmission, so having one’s own space is valuable, particularly as many have forgotten the necessity of wearing masks [43].

But on a longer timeline and with a wider lens, in order to fight climate change, society should also to move towards less car-dependent public transit and more mass public transit (trains, buses, or perhaps driverless ride-share taxis which pick up multiple riders), as well as micro-mobility. While single-occupancy taxis will have their use, there are better solutions for transportation if necessary steps are taken to redesign cities to tackle climate change [43].

Plus, there is the issue of labor – paid driverless taxis will put drivers out of a job, while that results in cost and efficiency savings for society as a whole, what it also does is forward that money away from drivers towards the owners of autonomous vehicles, whether that be individuals who can purchase robotaxis as Tesla envisions, or large companies who operate fleets like GM Cruise. As a society, it is needed to decide whether it’s a good or bad thing to concentrate the revenue from transportation into fewer hands or how to better distribute it [43].

Cruise is also now allowing riders to bring a guest on their trip (previously, rides were limited to just the account holder). Also, company’s “Cruise — Driverless Rides” iOS app is now available in the Apple App store via an invite code (see Fig. 18 below) to riders who have previously signed up for the public waitlist [44].

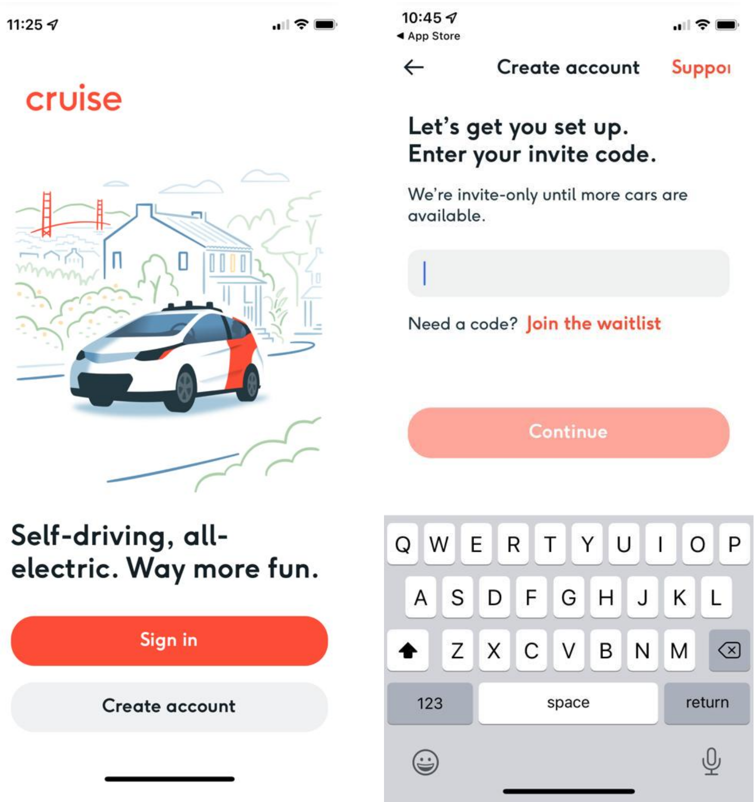


Fig. 18 - GM Cruise App

Driverless cars are still a long way away from the ubiquity and convenience of most ride-hailing services. But the progress in offering fared rides is still noteworthy. Cruise is not the first to charge a fee for rides; as already referred, Waymo, a spinoff from Google, has been charging for rides in its driverless vehicles in Phoenix, Arizona, as well as for rides in its autonomous vehicles with safety drivers in San Francisco. The company has yet to receive final approval to charge riders for trips in its driverless vehicles in the full city area [44].

Automotive and tech executives have long promised that autonomous vehicles would drive better than humans, but that wasn't the case for a fleet of Cruise cars in San Francisco in June 2022 [45]. Photos and a description of the Cruise robotaxis clustering and blocking several lanes of traffic in San Francisco were shared on Reddit and Twitter. At least seven Cruise vehicles can be seen clustering in the intersection of Gough and Fulton streets in the city's Civic Center neighborhood in a late Tuesday night, potentially blocking traffic both ways on one of the streets [45].

The incident is another example of how difficult is to develop and deploy self-driving vehicle fleets. Commercializing autonomous vehicles has been far more challenging than many predicted even a few years ago. The challenges have led to a consolidation in the autonomous vehicle sector after years of enthusiasm touting the technology as the next multitrillion-dollar market for transportation companies [45].

Alphabet-backed Waymo reportedly similar problems involving the clustering of its autonomous vehicles in the city. KPIX-TV, a CBS affiliate in San Francisco, reported in October that Waymo vehicles were getting stuck down a dead-end street.

Cruise's problem also comes months after an online video revealed a Cruise autonomous vehicle getting pulled over by police. In the video posted on April 1st 2022, the Cruise car initially pulled over to the side of the road and stopped as the officer approached the driver's side before it sped across an intersection and went further down the road [45].

Ensuring safer roads, new technologies will heavily disrupt the traditional motor vehicle insurance business, the impact of new technologies on the automotive industry, particularly the increasing adoption of semi-autonomous and fully autonomous vehicles technologies and the development of new patterns of mobility. It is anticipated that the frequency and severity of road crashes will significantly decrease with the introduction of fully autonomous vehicles [46]. Analysts estimate that by 2040, autonomous vehicles could lead to a 93% reduction in crashes. Such predictions bode well for the future of road safety, especially in High-Income Countries (HICs), where the adoption of new technologies has been quicker. Therefore, special consideration must be given to Low and Middle-Income Countries (LMICs), where the uptake is likely to take longer [46].

Analysts forecast motor insurance premiums to decline by 80% in some mature markets by 2040. New technologies also create new risks. It is expected that many risks will be transferred from individuals to vehicles and in-vehicle connected devices, which will involve vehicle manufacturers, technology providers and other stakeholders. In response to these developments, insurers are developing new business strategies and models [46].

Given the strong influence of motor insurance on driving behavior and crash prevention, the previous chapter aimed at illustrating how insurers can take further actions today to help improve road safety, both in HICs and in LMICs. In the coming years, the traditional motor insurance business is likely to be heavily disrupted by the cumulative effect of distinctive new trends: technology leading to the first autonomous vehicles, new shared mobility solutions, which question the need for car ownership, and digitalization and availability of a multitude of data related to mobility, and more broadly, regulatory, and global economic dynamics. Therefore, insurers need to continuously innovate and internalize new trends to remain relevant actors in road safety [46].

New technologies have already started to hit the automotive industry. The impending launch autonomous vehicles, which are designed to dispense a human driver and entrust driving tasks to a computer-based system, are the latest example. In fully autonomous mode, the driver will hand over responsibility for driving decisions to the vehicle and its associated technology, shifting the key accountable person in the insurance policy [46]. As most risks are related to human error, it is expected that eliminating this contributing factor would lead to a significant decrease in the probability of a crash occurring.

These innovations may have a direct impact on the market and the distribution of motor insurance: analysts forecast motor insurance premiums to decline by 80% in some mature markets by 2040. Many studies have been published that have attempted to forecast the expected and unprecedented overhauling of the motor insurance industry by smart and connected technologies. Such interest emphasizes the uncertainty about the future and underscores the ongoing creative thinking to determine what motor insurance might look in the future tomorrow.

Even though the speed and scale of the consequences of vehicle connectivity on the insurance industry remains uncertain, insurers are already anticipating significant changes and are starting to transform their traditional motor insurance business model [46].

Connected vehicles (CVs), corresponding to levels 1 and 2 of the internationally accepted classification for automated system set-up by SAE International, are already on today's roads. They are equipped with an advanced driver assistance system (ADAS), which is focused on crash avoidance, such as forward crash warning (FCW), autonomous emergency braking (AEB) or blind-spot information. They also are fitted with driver aids, like cruise control, lane-keeping assistant and parking assistant that contribute to reducing road risks and decreasing fatality and serious injury rates.

Swiss Re, a global reinsurer, and HERE, a location cloud company, analyzed the potential impact of selected ADAS features on road crash frequency, differentiating between motorways and other roads. The results demonstrated a significant impact of ADAS features on fatality rates:

- Basic ADAS (FCW, blind-spot detection and lane-departure warning) would reduce crashes on motorways by 16.3% and on other roads by 11.6%;
- Sophisticated ADAS (lane keeping assistant, AEB, night vision) would reduce crashes on motorways by 25.7% and on other roads by 27.5%;
- Advanced ADAS (highway pilot) would reduce crashes on motorways by 45.4% and on other roads by 27.5%.

Furthermore, it is expected that road risks, including crash frequency and severity, will continue to decrease with the introduction of fully autonomous vehicles (corresponding to level 5 of the SAE International classification). As mentioned before research shows that by 2040, autonomous vehicles could lead to a 93% reduction in crashes, and road safety will be significantly improved: by 2030, an estimated 720,000 lives could be saved from road traffic crashes thanks to connected cars [46].

The adoption of connected vehicles is being facilitated not only by technological advancement, but also by the growth of new mobility services. The latter reduce the need for individuals to own their car and enable mobility companies to increase their fleets of autonomous vehicles. Moreover, consumers seem prone to adopt these autonomous vehicles, as several studies show.

Swiss Re and HERE expected that by the early 20's more than two-thirds of cars sold worldwide will have some form of connectivity, while approximately 260 million connected cars will be on the roads. On this topic, it is important to note that the rise of new technologies may widen the road safety gap between HICs and LMICs, as there is likely to be a lag in the adoption of new driver assistance technologies and connected services in vehicles in LMICs. Current disparities between fatality rates may be further magnified, so special consideration needs to be given on how to fast track the adoption of effective technologies in LMICs [46].

Insurers can play an active role in mitigating the risks linked to vehicle factors by creating more attractive insurance policies dedicated to safer and/or more autonomous vehicles, which can prompt vehicle manufacturers to invest in connected security devices. New motor insurance business models are currently being developed, based on the exchange of data among the vehicle, connected services (e.g. onboard GPS) and road infrastructure.

The analysis of the data on these factors will help individualize the risks and build a more tailored and personalized motor insurance policy. In this regard, AXA is experimenting insurance solutions for new types of vehicles, like the "InsureMyTesla" policy, that offers tailor made protection to owners of Tesla electric cars in Hong Kong. It is also working on its preparedness to insure the future Google car and other autonomous vehicles. Similarly, Zurich is working with self-driving vehicle pilots, such as CityMobile2 in Europe, to better understanding of the risks associated with autonomous vehicles, which would help in designing appropriate insurance policies and services [46].

Furthermore, insurers need to take into account the new risks associated with digital systems (e.g., breakdowns, hacking, data theft) that could arise from autonomous vehicles. This typology of risks conveys the need to understand, prevent and reduce new risks, and the possibility of accumulated risk exposures (e.g., hacking of an entire fleet of autonomous vehicles). This latter may need to be addressed by pooling and diversifying risks from a large number of policyholders, including buying adequate reinsurance protection to cover large losses [46].

Based on the previous information, it can be seen in tables 7, 8 and 9 below, the concepts/properties found in GM Cruise – San Francisco instantiation mapped in the ontology concepts and relations as well as the competency questions answers found. There are direct mapping relations and instantiation concepts that map more than one ontology concept.

The ontology concepts from SAV ontology not found in the GM Cruise - San Francisco instantiation are shown in table 10 and discussed further on. As far as this research was conducted, it was not found any multiple concept instances that map in one ontology concept, or any concept found in San Francisco GM Cruise that is not defined in SAV ontology.

Table 7 – Concepts and relations found modelled in SAV ontology concepts - GM Cruise San Francisco

Sub-ontology	Domain	Ontology concepts	Matching Degree	Concepts found in San Francisco	Concept relations found in San Francisco
Ecosystem Efficiency Impact	Manufacturers Technical Development	Local SAV	Partial	Local SAV Service	Local SAVs (LSAVS) will require social acceptance.
Ecosystem Efficiency Impact	Urban Optimization	Policy/Pricing	Partial	Deployment methods and Policies to be in place	Deployment methods will influence Policies to be in place.
Social Impact	Government local authorities	Trust, Legislative and ethical clarification	Full	SAVs tech, law and ethics; Trust for full adoption	Trust in new Technologies will increase with legislative and ethical clarification in the way for full adoption trust.

Table 8 - Concepts and relations found modelled in more than one SAV ontology concept - GM Cruise San Francisco

Sub-ontology	Domain	Ontology concepts	Matching Degree	Concepts found in San Francisco	Concept relations found in San Francisco
Ecosystem Efficiency Impact	Manufacturers Technical Development and Urban Optimization	EV; AV; CV; MaaS; Traffic optimization; Efficiency increase	Full	Driverless and Efficiency	Driverless (Robotaxi, Shuttle, Self-driving, Level 5, Full automation) will increase efficiency.
Ecosystem Efficiency Impact	Urban Optimization	Traffic optimization; Low emissions; Efficiency increase	Full	Efficiency and Low Emissions	Fleet and traffic optimization reducing emissions (Going Green).
Ecosystem Efficiency Impact	Urban Optimization	Traffic optimization; Efficiency increase	Partial	Efficiency and Traffic reduced and optimized	More efficient traffic assignment extracting route flows and optimized travel time.
Social Impact	Regulatory authorities	Safety concerns and Safety increase	Full	Safety and Trust for full adoption	Trust for full adoption is hindered by safety concerns.
Social Impact	Users	Ownership; Individual characteristics	Partial	SAV service cost and AV private ownership cost	AV vs regular vehicle relative price will be influenced by WTP individual characteristics.

Table 9 – Competence questions responses in GM Cruise San Francisco instantiation

Competency Questions	GM Cruise San Francisco USA instantiation
CQ1: Which are the key concepts regarding Shared Autonomous Vehicles (SAVs)?	Autonomous Vehicles (AV) - possibility to be shared; Driverless - Robotaxi, Shuttle, Self-driving, Level 5, Full Automation; SAVs - shared autonomous vehicles, (CAVs) - connected autonomous vehicles; Mobility-as-a-Service
CQ2: What are the most important relations between them?	Trust for full adoption is hindered by safety concerns; AV vs regular vehicle relative price will be influenced by WTP individual characteristics; Understanding users' willingness for SAV services needs to cross psychological barriers in order to increase trust; Trust in new Technologies will increase with legislative and ethical clarification in the way for full adoption trust
CQ3: What impact on efficiency will SAVs bring to our society?	Efficiency increase using resources; Acceptance - SAVs services; Shared autonomous electrical vehicles (SAEVs)
CQ4: How could traffic optimization benefit from SAVs?	Safety increase - eliminating human error; Traffic - increase/assignment, extract route flows and travel time; Policy; Deployment methods will influence Policies to be in place. Green - fleet and traffic optimization reducing emissions; Urban optimization - new areas where before parking; Ridesharing - carsharing, ridepooling; Individual characteristics - opinion towards Avs; LSAVs - local SAVs

Table 10 - Concepts and relations from ontology not found in Cruise San Francisco instantiation

Sub-ontology	Domain	Ontology concepts	Concepts	Concepts relations not found
Ecosystem Efficiency Impact	Manufacturers Technical Development	SAEV	Charging - electrical vehicles EVs, SAEVs, monitoring battery, charging strategies	Shared autonomous electrical vehicles (SAEVs) charging strategies/battery monitoring optimization will increase efficiency.
Ecosystem Efficiency Impact	Urban Optimization	Congestion; Policy/Pricing	Congestion reduction and pricing	Efficiency regulates pricing, congestion reduction due to pricing increase along with traffic (tolling).
Ecosystem Efficiency Impact	Urban Optimization	Demand	Demand - induced, increment of trip demand	More trip-making demand is induced due to reduced parking demand.
Ecosystem Efficiency Impact	Urban Optimization	Policy/Pricing	Vehicle - assignment to the customers; Redistribution - vehicle	Ownership (private vs shared), will lead to different deployment methods and business models.
Ecosystem Efficiency Impact	Urban Optimization	Fleet - reduction	Fleet - reduction	AV/electrical vehicles (EV) shared mobility implies fleet reduction
Ecosystem Efficiency Impact	Urban Optimization	Parking	Urban optimization - new areas where before parking; Parking - area reduced and away from city centers	Parking reduction will lead to urban development in old parking areas, and land/energy consumption.
Social Impact	Government local authorities	Urban sprawl	Mobility enabler; Urban sprawl - AV repositioning from city centers	Commute longer distances
Social Impact	Government local authorities	Urban sprawl	Urban sprawl - AV repositioning from city centers	SAVs repositioning from city centres cause urban sprawl (longer commutes).
Social Impact	Government local authorities	Promoting - AV usage	Promoting - AV usage	User willing to pay (WTP) is higher in AVs with human driven option, causing SAVs usage dilemma.
Social Impact	Users	Individual characteristics	Individual characteristics - opinion towards AVs	Individual characteristics regarding aversion to sharing rides with strangers will slow full adoption trust.
Social Impact	Users	SAV shared ownership; AV private ownership	Ownership - reduction due to SAVs	Dynamic ridesharing/carsharing increase due to unwilling to pay for individualization.
Social Impact	Users	Endowment Effect	Endowment Effect	AV private ownership increases due to the fact that users values ownership more than WTP (Endowment Effect).
Social Impact	Users	Individual characteristics	Usage - choice decision	Understanding users' willingness for SAV services needs to cross psychological barriers in order to increase trust.

The ontology concepts not found in GM Cruise - San Francisco instantiation are probably due to the degree of development of SAV service is still quite new. It’s too soon to observe longer commutes, fleet reduction or urban sprawl. That will be a logical foreseen consequence of a more mature SAV service. Also, parking reduction and urban development in those free areas will happen if the current development trajectory continues. In the future it is also logical that more trip-making demand is induced due to the reduced parking demand. Efficiency will probably regulate pricing, implying congestion reduction due to pricing increase along with traffic (will need tolling).

With the increase in manufacturers' technical , it is expected that SAEVs charging strategies and battery monitoring optimization will increase efficiency.

It’s not easily foreseen if the endowment effect will appear or not, or if users willing to pay (WTP) is higher in AVs with human driven option or not, causing SAVs usage dilemma. For sure understanding users' willingness for SAV services needs to cross psychological barriers to increase trust.

7 Conclusion

In this research, we’ve conducted a systematic literature review, to identify relevant papers about key concepts regarding SAVs adoption and relations between them. Ideas was to compile and summarize important information and, to the best of our knowledge, SAV enablers overweight inhibitors. The following work included a reference ontology developed under Ontology Development 101 Methodology, where all 7 the steps [2] are clear and easy to understand, to have a formal representation of the SAVs domain. After following all the rules and suggestions, one of the most important things to remember is the following: there is no single correct ontology for any domain. Ontology design is a creative process and no two ontologies designed by different persons would be similar in its classes and properties definition.

We now know that several organizations and cities are already testing SAVs with the intention to deploy it large scale soon, the technologies that are being developed and used, and the main challenges about MaaS. This information helped us answer the best possible way to our research questions/competence questions and, by doing that, we now have a better idea of the challenges currently being faced to deploy the SAV model [37] [38] [39] [40].

Since the first deployment of SAVs is still a fairly recent subject, there are not many documents about it, and this research can be improved using studies that for sure will be released soon. On the other hand, given the number of automobile companies and top scientists researching the subjects of AVs and SAVs, there is a high risk of this document becoming outdated once it is finished.

Definitely, further research is needed to find the best SAV technical, ethical, operational and business model that users can trust and fully adhere to.

7.1 Contributions

The SLR part of this research was accepted by Springer book “Digital Technologies and Transformation in Business, Industry and Organizations”, ISBN 978-3-031-07625-1, as a chapter under publication.

In the current research we described in an organized form and using an ontology framework, the SAV impacts in our society, namely social impact and efficiency impact the vehicle's ecosystem.

7.2 Limitations

Ontology Development 101 can be considered a bit old nowadays. It’s not simply interchangeable with other methods and can be distinguished in the core approach, being between:

- Micro-level ontology authoring vs. a macro-level systems-view of ontology development.
- Isolated, single, stand-alone, ontology development vs. collaborative development of ontologies and ontology networks.

Micro-level methodologies focus on the viewpoint of the details emphasizing formalization aspects, which goes into ontology authoring, for it is about writing down the actual axioms and design choices that may even be driven by the language. Macro-level methodologies, on the other hand, emphasize the processes from information systems and IT viewpoint. They may merge into comprehensive methodologies in the near future [64].

Regarding the second difference, this reflects a division between ‘old’ and ‘new’ methodologies in the sense that the older ones assume a setting that was typical of 20 years ago: the development of a single monolithic ontology by one or a few people residing in one location, who were typically the knowledge engineers doing the actual authoring after having extracted the domain knowledge from the domain expert. The more recent ones take into account the changing landscape in ontology development over the years, being towards collaboratively building ontology networks that cater for characteristics such as dynamics, context, collaborative, and distributed development. For instance, domain experts and knowledge engineers may author an ontology simultaneously, in collaboration, and residing in two different locations, or the ontology may have been split up into inter-related modules so that each sub-group of the development team can work on their section, and the automated reasoning may well be distributed over other locations or remotely with more powerful machines [64].

Ontology Development 101 can be considered a ‘micro-level’ methodology: it focuses on guidelines to formalize the subject domain, i.e., providing guidance how to go from an informal representation to a logic-based one. While this could be perceived to be part of the macro-level approach, as it happens, such a ‘micro-level view’ actually does affect some macro-level choices and steps [64].

7.3 Future Work

Regarding future work would be interesting to validate if more SAV ontology concepts and relations will be present in SAV/AV environment when service will be mature and extended all American cities and even to other main cities around the globe.

Would also be interesting to evaluate this ontology in comparison to others in SAV/AV ecosystem, because this subject is evolving day by day, a much more complete SLR should be performed in order to update concepts and relations between them.

An update to the SLR with the newest papers from the SAV subject will be interesting to consider, this could improve the ontology also because new concepts or relations could be found.

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