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. This paper will focus on the development of a SAVs ontology.

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

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. Autonomous vehicles enable the greatest transformation in urban mobility since the automobile invention. 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. 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 [9]. In addition, SAVs are also expected to reduce accidents, reduce social exclusion and improve the utility of time on traveling [8].

Therefore, 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. The Design Science Research methodology (DSR) [7] was adopted to guide the development and evaluation of this ontology and as an artefact to define the terms and relationships between SAVs concepts. Moreover, 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).

2 Research Methods

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 described above in Fig. 1.

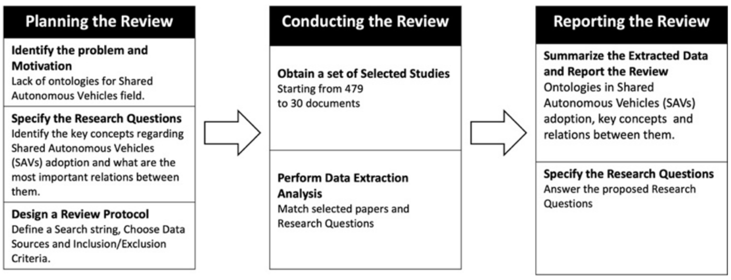


Fig. 1. - The SLR in 3 phases

Design Science Research (DSR) is a methodology in which the research answers relevant questions through the artefact's creation, contributing to new knowledge to the body of scientific evidence. In this environment, the designed artefacts are essential in understanding a real-life problem. This research follows the DSR methodology [7], which encompasses the steps depicted in Fig. 2.

The “Identify Problem & Motivate” outcomes were presented in the Introduction, as well as the “Define Objectives of a Solution”. The artefact 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”.

The methodological approach proposal integrates DSR and Ontology-development methodology, as presented in Fig. 2. First, the researcher has to follow the DSR to identify the problem and show its importance: the “Identify Problem & Motivate” DSR phase. Next, in the “Define Objectives of a Solution” DSR phase, the researcher studies which is the better artefact to meet the solution objectives, using the research questions. In the current case, the artefact identified to support solving the problem is an Ontology. Next, the researcher starts the “Design and Development” DSR phase [5]. 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” [5].

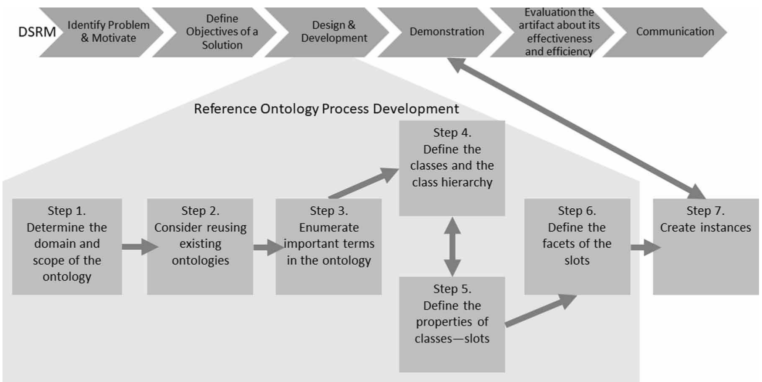


Fig. 2. DSR and Ontology-development methodology

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 [5]. 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 [2] was chosen, 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.

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].

3 Systematic Literature Review

This section of the report presents the execution of a systematic literature review. The presentation follows the three phases (Fig. 1) of the SLR - Planning, Conducting, and Reporting of the results.

Planning

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

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 between 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.

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

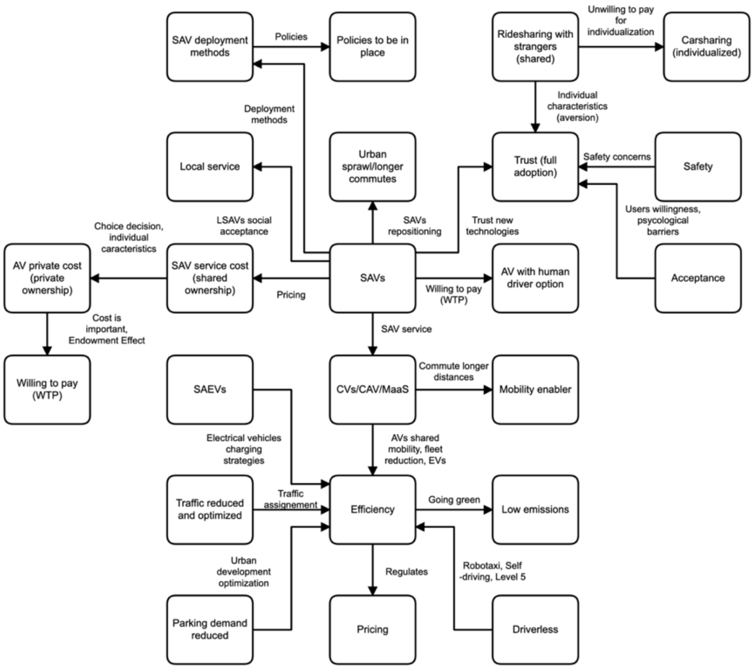
Element	Research Details
Source	EBSCO
Final Search String	Shared AND (“Model” OR “Metamodel” OR “Ontology” OR “Taxonomy” OR “Framework”) AND ("Autonomous" OR "Driverless" OR "Self-driving") AND ("Vehicle" OR "Car" OR "Auto" OR "Automobile" OR “Taxi” OR “Robo-Taxi” OR “Robotaxi” OR “Shuttle” OR “Cab” 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. 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.

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 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.

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

Fig. 3. – Concepts and Relations map



In Fig. 3, 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 SAV Ontology

The seven main phases in ontology development 101 methodology [2] are going to be implemented in this reference ontology, 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, the properties of each class (step five) and step the facets of the slots (step six) must be defined. The last step is the creation of the instances.

Step 1 -Determine the domain and scope of 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 shared understanding of the shared autonomous vehicles domain. This research will be approached from two main angles, technical/efficiency environment, and social/psychological impacts on users. This approach will be useful to describe the main 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?

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 my 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.

Step3 - Enumerate important terms in the ontology. It was summarized the terms and their descriptions, generating a dictionary of terms, as suggested in 101[2].

Step4 - Define the classes and the class hierarchy. Using the theoretical background described in the Step3, the class hierarchy was designed. This taxonomy uses the top-down approach [2]. This approach helps to define the more salient concepts first and then generalize and specialize them properly. 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 (see Fig. 4. below).

Step 5 - Define the properties of classes – slots. According to [2], the classes will not only provide enough information to answer the competency questions from step1, but they should also provide the internal structure of concepts and their properties. 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.

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.

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 the GM Cruise SAV deployment in San Francisco, USA. That will be detailed in next chapter.

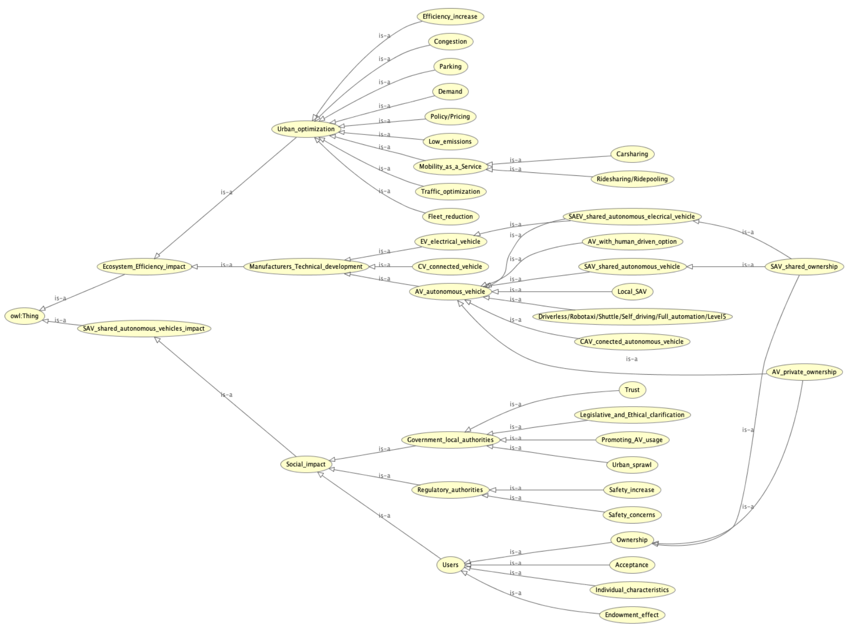


Fig. 4. - Taxonomy of SAVs ontology

5 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 this case a real commercial SAV service implementation in San Francisco, USA, the GM Cruise.

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. The California Public Utilities Commission (CPUC) voted to award Cruise with a driverless deployment permit, the final hurdle the company needed to jump to begin operating its autonomous ride-hail service commercially [6].

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, 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 [6]. 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 [6].

Based on the previous information, it can be seen in Tables 2. and 3. 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.

Table 2. Concepts and relations found modelled in more than one SAV ontology concept - GM Cruise San Francisco

Sub-ontology	Domain	Ontology concepts	Concepts found	Concept relations found
Ecosystem Efficiency Impact	Manufacturers Technical Development and Urban Optimization	EV; AV; CV; MaaS; Traffic optimization; Efficiency increase	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	Efficiency and Low Emissions	Fleet and traffic optimization reducing emissions (Going Green).
Ecosystem Efficiency Impact	Urban Optimization	Traffic optimization; Efficiency increase	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	Safety and Trust for full adoption	Trust for full adoption is hindered by safety concerns.
Social Impact	Users	Ownership; Individual characteristics	SAV service cost and AV private ownership cost	AV vs regular vehicle relative price will be influenced by WTP individual characteristics.

Table 3. – 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

6 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. Idea 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 the 7 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 two 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 in 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.

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