Consumer Adoption of Shared and Autonomous Vehicles in Lisbon Metropolitan Area

Joana Raquel Azinheira Vicente
Instituto Superior Técnico, Universidade de Lisboa, Portugal

Abstract

As result of the increasing challenges associated to mobility, connected, autonomous, shared and electric (CASE) vehicles have been emerging, having the potential to improve traffic conditions and cities and decrease harmful social and environmental impacts. To understand the potential adoption and related impacts of this technology in the Lisbon Metropolitan Area, a survey was conducted. The survey characterized the potential users, their typical trip and their level of acceptance through differences in time and cost/km. It was found that the acceptance is influenced by age, by the usual transport mode, by the travel period and by the experience with new shared mobility alternatives. Younger groups are the ones more willing to adopt CASE vehicles, as well as those that travel in rush hour periods and those that have previous experience with shared alternatives, while drivers are the group that shows less willingness to adopt. CASE vehicles would be accepted, in average, by 44,0% of the respondents. It was also seen that early adopters are aged between 18 and 35 years, including students, and that travel in rush-hour periods. The adoption can be increased with information spreading and financial incentives. The potential adoption would represent a cut in energy consumption of 17 PJ and decrease in 3 million ton CO_2 emissions. The impacts analysed may be different if people travel more kilometres due to an increase in travelling easiness.

Keywords: Vehicles, Connected, Autonomous, Shared, Electric, Adoption, Acceptance, Impacts

1.Introduction

1.1. Motivation

The comfort of owning and traveling in a personal vehicle has been leading to an increase of cars acquisitions along the years, also due to a strengthening of purchase power. In fact, between 1990 and 2016 the motorization rate increased from 185 to 470 vehicles per 1000 inhabitants, according to Pordata. This increase is noticed especially in cities, like Lisbon, and suburban agglomerates where thousands of people commute every day, with long traffic jams and excessive parked cars. In addition, cars circulate with an average occupation of 30%.

The environmental externalities are an increasing concern, according to EU Statistical Pocketbook 2018, 42% of the energy consumed in Portugal has transport sector as destination, which represents 6.8 million tonnes of oil equivalent. This consumption also means a yearly CO_2 emission of 21.9 million tonnes in Portugal and, regarding GHG, 22.1 million tonnes of CO_2 equivalent. Besides, road transport is responsible for local pollutant emissions, namely 39% of total NOx emissions in Portugal (EEA, 2019) and 63% of total NOx emissions in Lisbon[1] , as well as, 26% of CO emissions in Portugal and 78% of total CO emissions in Lisbon. These pollutants are a risk for human health causing thousands of premature deaths (EEA, 2019) and aggravate global warming. Besides, mental health can also be affected by traffic and noise[2].

While younger generations seem to care less about owning a car [3] new mobility alternatives emerge in the market such as CASE vehicles that combine several technologies and modalities in only one vehicle. A CASE vehicle is a connected, autonomous, shared and electric vehicle, that allows people to travel anywhere comfortably without the need for driving or owning a car.

A vehicle with these characteristics require certain cares regarding safety. Either due to the technological components since the vehicle will be connected to online platforms that can be hacked and is autonomous, being in this situation a hazard. But also at a more social level since there will inside the same vehicle people that do not know each other.

1.2. Objective

In this context, the objective of this thesis is analysing the potential consumer adoption of CASE vehicles in the context of Lisbon. In more detail, adoption profiles are defined to understand different adoption scenarios, define who the early adopters are, and also account for the impacts the adoption can have on the environment and what can be done to improve the adoption of CASE.

2. State of the art

2.1. Trends in urban mobility

To adapt to environmental goals internationaly established world's cities have been facing changes in the transport systems. These changes are seen in the apearence of vehicle sharing service, sush as electric car or bike sharing. Some cities have already in use prototypes for autonomous electric shuttles (Navya Website, 2019) (EasyMile Website, 2019). Regarding Mobility as a Service (MaaS) have already been increasing in the later years [4] with ride-hailing and sharing services and are expected to keep on growing, acording to Statista.

Another evidence that cities have been upgrading their systems to support a more sustainable mobility is the fact that the number of recharging points for electric vehicles have been increasing and are expected to keep on growing, a signal that the city of Lisbon is evolving (CML website, 2019). On the other hand, to adopt autonomous connected vehicles all the city infrastructure must be adapted in order to allow seamless vehicle movement.

In oposition of what may come to mind at first when CASE vehicles are a reality the number of vehicles and kilometres travelled shall increase since travelling will get a lot easier than it is today [5], but traffic would be more organized. However, to transform the city's mobility into a sustainable urban mobility it is necessary to approach the problem multidimensionaly to cover from structural aspect to social and cultural assets [6]. The biggest challenges for adoption fall then on the adaptation of the city infrastructures and the acceptance from users [7].

2.2. Acceptance and adoption of alternative mobility products

To understand how to introduce in a society meaningful changes in transportation is frequently used a Multi-level Perspective [8]that considers three evolution levels:

- Niches: Where is precepted how the innovation works, who will be the fundamental actors, usually restrained to researchers, buyers and military.

- Socio-technical regimes: Besides the actors, it is necessary to adapt the whole system in order to have every aspect converging to the adoption.
- Socio-technical landscape: It is then necessary to consider the economic system and urban forms.

Technology Acceptance Model hypothesizes that the perceived ease of use and usefulness is what pulls the trigger to acceptance [9]. Therefore, for the CASE technology to succeed, it is necessary to make people understand the benefits CASE vehicles can have on society.

Studies have been done to understand the acceptance of autonomous and shared vehicles. The studies for autonomous vehicles showed that the level of acceptance decrease with the level of automation [10]. Also on shared autonomous vehicles [11] state that smaller vehicles are more likely to be accepted since it would transport less people. User age, education, income and time spent driving can also affect the acceptance [12].

It is important to spread information about the new mobility products for their acceptability, for that the right actors have to take the lead. In a digital era, trendsetters could have a key role [13]. An intelligent use of current technologies, such as smart phones, to improve the use of future technologies may be crucial for their success [14]. In the end, the choice is dictated by a personal will. Financial incentives may help the way to make the most environmental friendly choice.

At the same time, it is necessary to give some guarantee of road safety for people, either inside the vehicle or for pedestrians. The solution for hacking problems may come from more developed industries such as aviation [15]. Whereas legislation can help gain some security about the technology adoption and it would be essential for a society to function with these technologies, in fact some countries already are preparing legislation for testing and commercialize autonomous vehicles.

Besides, understanding the positive impacts on environment may be essential. For that matter, some studies have been made. A system of car sharing with electric vehicles can save, in a country with approximately the same population as Portugal, as it is the case of Sweden, 188% CO_2 emissions (Figure 1) compared with the saving a system with petrol vehicles [16].

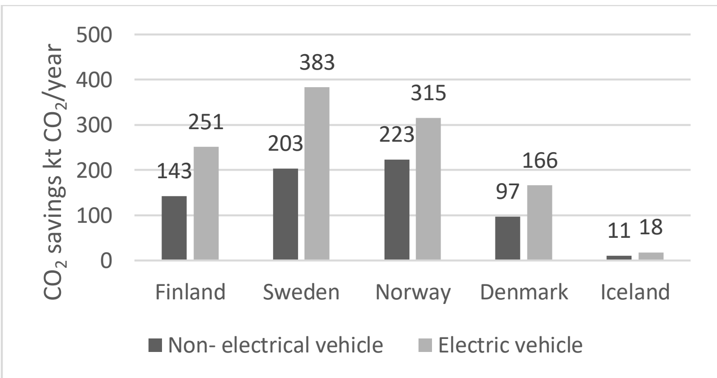

Figure 1-CO2 savings with car sharing (Source: Mobility as a Service and Greener Transportation Systems in a Nordic context)

A study made to a mid-size city show that the adoption of autonomous vehicles can represent energy savings of 12%[17]. The same study shows that pollutant emission can also decrease as seen in Table 1, when the autonomous vehicle have an internal combustion engine.

Table 1- Pollutant emissions savings with autonomous vehicles (Source: The travel and environmental implications of shared autonomous vehicles, using agent-based model scenarios)

	GHG	SO_2	CO	NO_x	VOC	PM_{10}
Kg	5,1	5,9	1287	43	88	1,8
%	5,6	16	34	18	49	6,5

3. Data and Methods

3.1. Case study description

In this work the case study is Lisbon Metropolitan Area (LMA) where the average trip that lasts 25 minutes and takes 11 Km is 60% of the times done in a private car and 30% has "Work" as motive. These 35% of these movements have diferent municipalitiesas as origin and destination and the mobile population is evenly distibuted between men and women. To better understand the possible acceptance of CASE vehicles a survey was developed and deployed on the LMA.

3.2. Survey design and implementation

For the purpose of the survey, CASE vehicles were defined as shared autonomous vehicles that would facilitate the daily mobility decreasing costs for travellers and travel times. The survey was divided in three parts. The first one is the typical trip characterization. The second part is a choice activity where the respondent has to pick in 8 possible scenarios between 3 different variable alternatives and the third part annotates information about the inquired.

3.2.1. Scenario definition

For the scenario definition three alternatives were considered to present as simple vehicle solutions during the survey.

- **Alternative 1** - consists on the conventional private gasoline car and is presented as the current solution;
- **Alternative 2** introduces an autonomous electric vehicle, connected to the users' cell phone that with a mobile app would be able to book the trip and the vehicle. The vehicle will then pick the user up in their location and drive them to the final destination. During all the trip, the user would be alone in the car;
- **Alternative 3** is in every aspect the same as Alternative 2 except that in this last option the user shares the trip with other users, which implies more stops along the trip.

The cost for each alternative was computed accounting all the expenses in a vehicle lifetime, namely, vehicle acquisition, energy, maintenance, insurance, tolls and parking and the kilometres that each vehicle should travel along the years. The results for all these calculations are presented in Table 2.

After that an interval in which prices and durations may fall in the future were defined to present in different scenarios in the survey. Based on assumption from the literature, the prices were assumed to be 20% below or above the established an time was assumed to be 4 minutes shorter or longer than established.

Table 2-Table presented on the survey, corresponding to the calculated scenario

	Convencional private vehicle	Autonomous electric vehicle (car-sharing)	Autonomous electric vehicle (ride-sharing)
	Alternative 1	Alternative 2	Alternative 3
Trip cost (€/km)	0,36	0,27	0,07
Total trip time (min)	25	29	33

3.3. Data processing for impacts quantification

To process the survey results it was used Microsoft Excel and SPSS. Excel was used to understand how the variables affect each other, which were the preferences and understand the respondent profile and daily trip, whereas in SPSS it was tested the statistic relevance of some variables in other variables. The tests run in SPSS had the intention to verify the normality, variance homogeneity and the effect each variables had in one another. For that, the tests used were Shapiro-Wilk for normality since the sample has more than 100 individuals and Levene for variance homogeneity. Then as the data was not normal, the tests used to compare variables were Mann-Whitney when the grouping variable had only two groups, Kruskal-Wallis when the grouping variable had more than two groups and Spearmen correlation when the variable to analyse was a rate.

To quantify the impacts of a potential adoption is necessary to define adoption scenarios. Two adoption scenarios were defined based on the behaviour during the choice activity. The first scenario is considered a first stage adoption, where are accounted as early adopter those who choose alternative 3 all along the activity. The second scenario accounts with all the respondents that chose alternative 3 at least half of the experience (4 times).

With the scenarios defined it is computed how many common vehicles (cars, motorcycles, buses) are traded for CASE vehicle in each scenario. Using the occupancy rates previously calculated and considering a CASE vehicle with 4 occupants is calculated how many CASE vehicles are necessary to substitute the regular vehicles (Equation 1 and 2). To do this it should be considered which type of vehicle each respond use to travel in in their typical trip. After that, is calculated the energy and pollutant emissions that can be saved according to emission factors previously showed.

Equation 1-number of vehicles in a first stage scenario

$$number\ of\ vehicle\ _1 = number\ of\ vehicles_0\ * (1 - percentage\ of\ acceptance)$$

Equation 2-number of CASE vehicles in a first stage scenario

$$CASE = \sum (\ number\ of\ vehicles_0 - number\ of\ vehicle\ _1) * \frac{vehicle\ occupancy}{4}$$

The assumed pollutant emission and energy consumption for common transport modes are presented in

Table 3.

Table 3-Vehicles emissions (g/km) and energy consumption (MJ/km)

Vehicle	**CO_2**	**HC**	**CO**	**NO_x**	**PM**	**MJ**
LDV gasoline	203,39	0,30	2,04	0,48	0,04	2.9
LDV diesel	198,01	0,07	0,39	0,53	0,06	2.7
Motorcycle	125,20	0,18	0,70	0,07	0,01	1.8
Buses	1230,51	0,07	2,12	8,73	0,20	16.5
Train	1885	-	-	-	-	3.6
Metro	3063	-	-	-	-	9.4

Then knowing the km travelled in on year for each vehicle category it is possible to know the emissions in one year.

For the quantification of impacts associated to the adoption scenarios, was assumed that electricity production is 100% renewable. For that reason and in addiction to the fact that the objective is to create a MaaS system, train and metro emission and kilometres are not accounted for change in the km travelled. However, it should be considered that people that travel by that modes can adopt CASE vehicles as well.

4. Results and Discussion

4.1. Survey results

The survey was opened for answers from 30 of July 2019 to 22 of August 2019 obtaining 354 answers from which 250 were complete, valid and analysed.

The variables considered by SPSS tests to be significantly different were respondent's age, usual transport mode, travel period and experience with shared alternatives. As the differences between those who commute inter or intra-municipally are not meaningful, the same variables were run in separate showing also differences. For both tests it was seen that older people are more reluctant to accept CASE vehicles. While according to transport mode those who use to drive are the ones less likely to adopt shared autonomous vehicles. People that travel during both rush-hour periods are the ones that prefer CASE vehicles. Those who are not willing to try shared mobility alternatives are the ones that do not want to adopt shared autonomous vehicles.

72 out of 250 respondents (28.8%) opted for alternative 3 all along the experience, despite increases or decreases, in relation to the other two alternatives, in time and price. These 72 respondents corresponds to 29% of the sample and correspondents to a more optimistic adoption scenario. From those, 36 use car, 28 use public transports, and 7 use to walk or take a bike and only one uses a motorcycle. The said adopter represent 23.1%, 37.8%, 46.7% and 33% of the respective groups. It is important to take into consideration that only 55.3% of those who commute by public transportation uses bus, which was considered in the following vehicle and emission calculations.

The group considered to be the second stage adopters correspond to 16.0% of the sample (40 out of 250), from which 25 are car users, 13 public transport users and 2 people use to walk or take a bicycle. This corresponds to a more conservative scenario. However, to understand the impacts this second stage has on the current situation, the adoption rate that should be consider includes the early adopters and the second phase adopters. So, that was the acceptance values used to calculate the second stage adoption impacts. Therefore for a second stage adoption it was considered that 38.6% (61 out of 161) of people that uses car daily were willing to adopt CASE vehicles, one that uses motorcycle (33.3%), 41 people that takes public transportation (55.4% of those who uses public transports) and 60% (9 people) that use to walk.

The profile of the early adopters is not well defined, however 40.8% of people aged between 18 and 25 years and 37.0% of those between 26 and 35 years opted for alternative 3 every time representing 29 of the 72 people considered as early adopters. 40.0% of the traveller in the afternoon rush-hour period and 35.6% of those who travel in the morning period also opted for alternative 3 all along the survey. 37.1% of the students are considered early adopters. Also 35.1% of those who commute intra-municipally choose alternative 3 in the eight tables.

4.2. Impacts of obtained adoption scenarios

For impact analysis were considered two adoption stages. The first one considers people that chose CASE vehicles all along the experience, designated the early adopters. The second considers the first and those who chose CASE vehicles at least half of the times.

In the first stage the reduction in kilometres travelled in a year is in the order of billions for cars with about 1,5 billion for gasoline cars and 1,8 for diesel cars while for buses and motorcycles the reduction is the order of millions with 22 million for motorcycles and 78 million for buses. However, there is an increase of 17 billion km travelled in CASE vehicles, representing a total increase of 13 billion kilometres, considering all the vehicles in circulation in this scenario as seen in Table 1.

For energy consumption, with fossil sources, there is total decrease of circa 10 PJ, a cut of 242 kton in fuel sales, however CASE vehicles will consume 12 PJ. This should mean a depletion of pollutants emitted with a decrease of about 763 kton of CO_2, 595 ton of HC, 6824 ton of NOx and 189 ton PM. This differences represent decreases of 23% in relation to the current situation for cars, 33% for motorcycles and 21% for buses.

Table 4-Differences after a first stage adoption in annual kilometres, passenger kilometres, energy consumption and pollutant emissions

Difference	**km/year**	**pass.km**	**Energy consumption (PJ)**	**Emissions (kton)**				
				CO_2	HC	CO	NOx	PM
LDV gasoline	1,55E+09	2,48E+09	4,48	315,21	0,46	5,96	0,75	0,06
LDV diesel	1,76E+09	2,82E+09	4,67	348,72	0,13	0,68	0,94	0,11
Motorcycles	2,17E+07	2,17E+07	0,04	2,72	0,004	0,02	0,001	0,0001
Buses	7,84E+07	6,67E+09	1,29	96,51	0,01	0,17	0,68	0,02
CASE	-1,65E+10	-6,62E+10	-11,91	-	-	-	-	-

After the second stage the reduction in kilometres travelled, when compared with the current situation is, of 2.6 billion km for gasoline cars and 3 billion km for diesel cars, 22 million km for motorcycles and 115 million for buses. CASE vehicles should run 27 billion kilometres, an increase of about 23 billion kilometres when compared with the current situation.

The total energy consumption reduction is about 17 PJ which corresponds to a decrease of 363 kton of fuel consumed, however CASE vehicles will consume 20 PJ which represents. Accounting the pollutant emission, the potential reductions is of 3 million ton of CO_2, 2612 ton of HC, of 17667 ton of CO and 834 ton of PM. Table 5 presents the precentral differences relative to the mentioned values. This differences represent decreases of 39% in relation to the current situation for cars, 33% for motorcycles and 30% for buses.

Table 5- Differences after a second stage adoption in annual kilometres, passenger kilometres, energy consumption and pollutant emissions

Difference	**km/year**	**pass.km**	**Energy consumption (PJ)**	**Emissions (kton)**				
				CO_2	HC	CO	NOx	PM
LDV gasoline	2,62E+09	4,20E+09	7,6	533,64	0,78	7,57	1,26	0,10
LDV diesel	2,98E+09	4,77E+09	7,9	590,37	0,21	1,15	1,59	0,19
Motorcycles	2,17E+07	2,17E+07	0,0	2,72	0,004	0,02	0,001	0,0001
Buses	1,15E+08	9,77E+09	1,9	141,44	0,01	0,24	1,00	0,02
CASE	-2,71E+10	-1,09E+11	-19,5	-	-	-	-	-

The verified increase in travel v.km is only due to the extra kilometres calculated for the functioning of a CASE vehicle. Although, it is necessary to consider what was mentioned in 2.1 Trends in urban mobility. The ease to travel may increase the number of trips, which will increase the number of kilometres travelled and of vehicles needed. However, there was not a question on the survey that allows an estimation for that increase. It is also necessary to consider that from public transport responders 22.8% use train and 21.9% use metro. Those where not considered for the calculations since with MaaS the idea is to conjugate CASE vehicles with existing carbon free public transports. If the production of electricity is 100% renewable the energy source for metro and train will not emit CO_2 as well. However, if some of those users decide to use CASE vehicles instead of the usual transport the number of vehicles and kilometres travelled may increase.

5. Conclusions and future work

The objective of this thesis was to analyse the potential consumer adoption of CASE vehicles and characterization of possible early adopters and the related environmental and social impacts. To fulfil the objective the current state of the art was investigated, followed by a survey on potential users' preferences and the assessment of the answers to compute the associated environmental impacts.

It was seen that some progress has been made so far on the adaption of cities to the mobility technologies that have been available in market for a few years such as electric vehicles. Some autonomous vehicles are already available as prototypes in some cities, however to adopt autonomous vehicles as a common car or shuttle it is necessary to prepare legislation common to the surrounding countries, an example may be legislation in common for EU countries and cities infrastructures. It was also understood that to introduce CASE vehicles the needed changes in the several dimensions of the problem must be addressed. As an example besides considering the technical work needed to adapt infrastructures, and all the IT knowledge behind an autonomous shared vehicle is necessary to consider the socio-cultural aspects and the economy of the regions.

To improve the acceptance of new vehicles the transport system and policies should converge towards an easy adoption. Another important step is disseminating the positive impacts of CASE vehicle on the environment and society. Making CASE vehicles easier to use and available for everybody alongside with implementing in society a perception of usefulness will certainly help the acceptance. Safety is important for the acceptance so a guarantee of safety of the users and non-users should encourage the adoption. Another way to encourage CASE vehicles adoption are incentives, as are already applied to other technologies.

A CASE vehicle that should present a cost of 7 cents/km in a 33 minutes trip had in the deployed survey an average acceptance of 44,0%. The choice for CASE vehicles is affected by age, with younger people being more prone to adopt. In fact, people aged below 35 present more than 50% choice in alternative 3 while for older groups the percentages of choice is more distributed. Transport mode where people that usually drive are the group with less preference for CASE vehicles since in average drivers are divided between the 3 alternatives presenting an average of 36,0% of choice in alternative 3, while all the other groups present a percentage of choice above 50%. Travel period also represents differences in alternative choice where people that travel out of the rush-hour period prefer CASE vehicles less, with only 26,2% of the non-rush-hour commuter choice. Another aspect that has showed to affect the choice is the previous experience with shared mobility alternatives already available with those who state that would not like to try showing a clear preference for keep on using the current alternatives. It was not considered that the differences between intra and inter-municipal commuting were meaningful. When choosing between mobility alternatives. Despite not being a well-defined profile, it possible to admit that the early adopters are people aged between 18 and 35 years old. This agrees with the fact that students are an important early adopters group. Besides, rush hour commuters are seen as early adopters.

Considering people that chose CASE vehicles all along the choice activity as the early adopters, in a first stage adoption and in a second stage those that chose CASE vehicles at least half of the experience (4 times), energy consumption in AML could decrease up to 17 billion MJ. CO2 emission could also reduce in 3 million tons along with thousands of tons of local pollutants. This is based in a reduction of vkm and number of combustion vehicles of 310662. The number of CASE vehicles at the second stage is 240746 that could increase due to a rebound effect since kilometres travelled by one individual would possibly increase as travelling would get easier and potentially cheaper.

The positive impacts of a potential adoption of CASE vehicles may be important to contribute to a healthier environment.

That being said, as future work the following aspects can be assessed:

- The influence time and price have on the choice of these vehicles can be estimated through a discrete choice model;
- A study to understand the change in travelling patterns with an autonomous shared vehicle to quantify the difference in kilometres travelled by each person and their the schedules.
- Expand this study to Oporto Metropolitan Area, or even to all the country to understand if smaller cities would respond evenly.

6. References

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